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[TITLE OF THE INVENTION] STAGE UNIT AND EXPOSURE APPARATUS

[CLAIMS]

[Claim 1] A stage unit comprising:

a substrate holding member which holds a substrate; and

a substrate stage which moves two dimensionally with the substrate holding member mounted thereon, and on which a plurality of fiducial marks are arranged dispersed with respect to each of measurement sequences using the fiducial marks so that a positional relationship between each of the fiducial marks and the substrate holding member is constant.

[Claim 2] The stage unit according to claim 1, characterized in that the plurality of fiducial marks are at least three fiducial marks each of which is arranged in the vicinity of one of vertex positions of a polygon containing a center of the substrate holding member.

[Claim 3] The stage unit according to claim 1, characterized in that the plurality of fiducial marks include a first fiducial mark and a second fiducial mark which are arranged on a straight line passing through a center of the substrate holding member and on opposite sides with respect to the center.

[Claim 4] The stage unit according to any one of claims 1 to 3, characterized by further comprising a plurality of fiducial mark plates which are arranged on a

periphery of the substrate holding member on the substrate stage, and in each of which at least one of the fiducial marks is formed.

[Claim 5] An exposure apparatus which exposes a substrate with an energy beam and forms a predetermined pattern on the substrate, the exposure apparatus comprising:

a substrate stage which moves two-dimensionally;

a substrate holding member which is mounted on the substrate stage and which holds the substrate;

a plurality of fiducial mark plates on which a plurality of fiducial marks are dispersedly arranged with respect to each of measurement sequences using the fiducial marks, and which are arranged on a periphery of the substrate holding member on the substrate stage so that a positional relationship between each of the fiducial marks and the substrate holding member is constant;

a mark detection system which detects marks located on the substrate stage; and

a control unit which performs various types of measurement sequences each including a detection operation to detect at least one of the plurality of fiducial marks using the mark detection system.

[Claim 6] The exposure apparatus according to claim 5, characterized by further comprising a position measurement unit which manages a position of the substrate

stage on an orthogonal coordinate system;

wherein the plurality of fiducial mark plates include a first mark plate on which a plurality of fiducial marks are arranged along a first axis direction on the orthogonal coordinate system, the first mark plate being an elongated plate extending in the first axis direction, and a second mark plate on which a plurality of fiducial marks are arranged along a second axis direction orthogonal to the first axis direction, the second mark plate being an elongated plate extending in the second axis direction.

[Claim 7] The exposure apparatus according to claim 6, characterized by further comprising:

a mask stage which holds a mask having the pattern formed therein;

a drive unit which synchronously moves the mask stage and the substrate stage along the second axis direction; and

a pair of mask-mark detection systems which measure at least one pair of mask marks formed on both sides of the pattern on the mask in the first axis direction;

wherein a length of the first mark plate in the first axis direction corresponds substantially to a distance between the pair of mask marks; and

a length of the first mark plate in the second axis direction is slightly greater than a length required to form the fiducial marks.

[Claim 8] The exposure apparatus according to claim 6, characterized by further comprising:

a mask stage which holds a mask having the pattern formed therein;

a drive unit which synchronously moves the mask stage and the substrate stage along the second axis direction;

a mask side position measurement unit which measures a position of the mask stage; and

a mask-mark detection system which measures a plurality of pairs of mask marks formed on both sides of the pattern on the mask in the first axis direction;

wherein a length of the second mark plate in the second axis direction corresponds substantially to a length of the pattern in the second axis direction; and

a length of the second mark plate in the first axis direction is slightly greater than a length required to form the fiducial marks.

[Claim 9] An exposure apparatus which exposes a substrate with an energy beam and which forms a predetermined pattern on the substrate, the exposure apparatus comprising:

a substrate stage which moves two-dimensionally;

a position measurement unit which measures a position of the substrate stage;

a substrate holding member which is mounted on the substrate stage and which holds the substrate;

at least three fiducial marks each of which is arranged in the vicinity of one of vertex positions of a polygon containing a center of the substrate holding member, and which are arranged on the substrate stage so that a positional relationship between each of the fiducial marks and the substrate holding member is constant;

a mark detection system which detects marks located on the substrate stage and including the fiducial marks; and

a control unit which performs various types of measurement sequences each including a detection operation to detect one fiducial mark or a plurality of fiducial marks among the at least three fiducial marks using the mark detection system and the position measurement unit.

[Claim 10] The exposure apparatus according to claim 9, characterized by further comprising a plurality of fiducial mark plates on each of which at least one of the fiducial marks is formed, the fiducial mark plates being arranged on a periphery of the substrate holding member on the substrate stage.

[Claim 11] The exposure apparatus according to claim 10, characterized in that the at least three fiducial marks are arranged on the plurality of fiducial mark plates to be dispersed with respect to each of measurement sequences using the fiducial marks.

[Claim 12] The exposure apparatus according to claim 10 or 11, characterized in that a position of the

substrate stage is managed by the position measurement unit on an orthogonal coordinate system; and

the plurality of fiducial mark plates include a first mark plate on which a plurality of fiducial marks are arranged along a first axis direction on the orthogonal axis system, the first mark plate being an elongated plate extending in the first axis direction, and a second mark plate on which a plurality of fiducial marks are arranged along a second axis direction orthogonal to the first axis direction, the second mark plate being an elongated plate extending in the second axis direction.

[Claim 13] The exposure apparatus according to claim 9, characterized in that each of the at least three fiducial marks is formed in the substrate holding member.

[Claim 14] An exposure apparatus which exposes a substrate with an energy beam and which forms a predetermined pattern on the substrate, the exposure apparatus comprising:

a substrate stage which moves two-dimensionally;

a position measurement unit which measures a position of the substrate stage;

a substrate holding member which is mounted on the substrate stage and which holds the substrate;

at least two fiducial marks including a first fiducial mark and a second fiducial mark which are arranged on a straight line passing through a center of the substrate

holding member and on opposite sides with respect to the center, and which are arranged on the substrate stage so that a positional relationship between each of the fiducial marks and the substrate holding member is constant;

a mark detection system which detects marks located on the substrate stage including the at least two fiducial marks; and

a control unit which performs various types of measurement sequences each including a detection operation to detect one fiducial mark or a plurality of fiducial marks among the at least two fiducial marks using the mark detection system and the position measurement unit.

[Claim 15] The exposure apparatus according to claim 14, characterized by further comprising a plurality of fiducial mark plates which are arranged on a periphery of the substrate holding member on the substrate stage, and on each of which one of the at least two fiducial marks is formed.

[Claim 16] The exposure apparatus according to claim 15, characterized in that the at least two fiducial marks are arranged on the plurality of fiducial mark plates to be dispersed with respect to each of measurement sequences using the fiducial marks.

[Claim 17] The exposure apparatus according to claim 15 or 16, characterized in that a position of the substrate stage is managed by the position measurement unit

on an orthogonal coordinate system; and

the plurality of fiducial mark plates include a first mark plate on which a plurality of fiducial marks including the first fiducial mark are arranged along a first axis direction on the orthogonal axis system, the first mark plate being an elongated plate extending in the first axis direction, and a second mark plate on which a plurality of fiducial marks including the second fiducial mark are arranged along a second axis direction orthogonal to the first axis direction, the second mark plate being an elongated plate extending in the second axis direction.

[Claim 18] The exposure apparatus according to claim 14, characterized in that each of the at least two fiducial marks is formed on the substrate holding member.

[Claim 19] The exposure apparatus according to any one of claims 14, 15, 16 and 18, characterized in that a position of the substrate stage is managed by the position measurement unit on an orthogonal coordinate system; and the straight line connecting the first fiducial mark and the second fiducial mark is tilted at an angle of approximately 45 degrees with respect to both coordinate axes of the orthogonal coordinate system.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[TECHNICAL FIELD TO WHICH THE INVENTION BELONGS]

The present invention relates to a stage unit and an exposure apparatus. More particularly, it relates to an exposure apparatus which performs exposure on a substrate with an energy beam so as to form a predetermined pattern on the substrate and a stage unit which can be suitably applied to the exposure apparatus.

[0002]

[CONVENTIONAL ART]

Conventionally, in a lithographic process to manufacture, for example, a semiconductor device, a liquid crystal display device and the like, an exposure apparatus is used which transfers a pattern formed on a mask or a reticle (hereinafter generally referred to as a "reticle") onto a wafer or a glass plate (hereinafter generally referred to as a "wafer") via a projection optical system. In recent years, due to higher integration of the semiconductor device, the type of projection exposure apparatus which moves step by step such as the reduction projection exposure apparatus based on the step-and-repeat system (the so-called stepper) and the scanning type projection exposure apparatus, which is an improvement of the stepper, based on the step-and-scan system (the so-called scanning stepper) or the like has become mainstream.

[0003] The semiconductor device or the like is made by overlaying patterns in a plurality of layers (in a multiple layers). Therefore, with the exposure apparatus such as the stepper the overlay of the pattern formed on the reticle onto the pattern already formed on the wafer needs to be highly accurate. This requires a precise measurement of the position on the wafer of the shot area where the pattern is formed, and for the precise measurement a method which uses a variety of position measurement sensors to measure the position of alignment marks arranged along each shot area is employed.

[0004] Furthermore, for this measurement, as a reference for measuring the positional relationship between the reticle, the projection lens, and the wafer a fiducial mark plate on which various types of fiducial marks are formed is arranged in the vicinity of the wafer on the wafer stage which holds the wafer.

[0005] Normally, one fiducial mark plate is arranged on the wafer stage, and by measuring the fiducial marks formed on the fiducial mark plate, the relative distance between position measurement sensors is managed as well as the orthogonal degree of the stage interferometer which measures the position of the stage and the conversion rate used for figuring out the distance from the interference fringe count measured with the stage interferometer.

[0006]

[PROBLEM TO BE SOLVED BY THE INVENTION]

In a case, however, when measurements for these controls are performed using a single fiducial mark plate, there is a fear that the measurement accuracy might decrease since the span of the measurement distance is limited by the size of the fiducial mark plate.

[0007] Therefore, as a means of improving the measurement accuracy, it is possible to consider increasing the size of the fiducial mark plate. There is, however, a concern that this might lead to a larger stage size. Especially, with the exposure apparatus recently gathering attention that includes a plurality of substrate stages, since the stages require an extremely large driving range, and the footprint of the apparatus naturally has to increase, thus causing an inconvenience that the footprint of the apparatus is consequently increased.

[0008] Furthermore, with the exposure apparatus including a plurality of substrate stages as is referred to above, in most cases the exposure apparatus includes only one optical system for exposure, and in such a case there is a tendency of the exposure position and the alignment position being far apart so as to prevent interference between stages from occurring. This makes the optical axis of the interferometer measuring the position of the stage between the exposure position and the alignment position stray or is removed from the stage. Nevertheless, even in

such a case, the relative position of the substrate on the stage with respect to the optical system for exposure and/or the mask needs to be managed or controlled with good accuracy.

[0009] The present invention has been made in consideration of the circumstances described above, and has as its first object to provide a stage unit which can be downsized (made small) while maintaining its measurement performance.

[0010] It is the second object of the present invention to provide an exposure apparatus in which substrate stage thereof can be downsized as well as the footprint of the apparatus reduced.

[0011] Further, it is the third object of the present invention to provide an exposure apparatus in which substrate stage thereof can be downsized and the footprint of the apparatus reduced, and which is also capable of controlling or managing the position of the substrate with good accuracy at all times.

[0012]

[PROBLEM TO BE SOLVED BY THE INVENTION]

According to the invention according to claim 1, there is provided a stage unit comprising: a substrate holding member (H1, H2) which holds a substrate (W1, W2); and a substrate stage (WST1, WST2) which moves two dimensionally with the substrate holding member mounted thereon, and on

which a plurality of fiducial marks (Ma1 to Md, or Mh, Mi) are arranged dispersed with respect to measurement sequences each using the fiducial marks so that a positional relationship between each of the fiducial marks and the substrate holding member is constant.

[0013] With this stage unit, a plurality of fiducial marks are arranged dispersed with respect to (per or by) measurement sequences each using the fiducial marks so that the positional relationship between each of the fiducial marks and the substrate holding member is constant. Therefore, for example, the fiducial marks can be respectively arranged apart at a certain interval on a periphery of the substrate holding member. This makes it possible to sufficiently secure the interval (distance) between the fiducial marks, relax the limitations on the measurement span, and consequently, improve the measurement accuracy. In addition, the respective fiducial marks can be arranged on the substrate stage even at a small space on the substrate stage. Since the plurality of fiducial marks are arranged dispersed by each measurement sequence which uses the fiducial marks, the performance regarding measurement can be maintained. Accordingly, the stage can be downsized while maintaining its measurement performance.

[0014] In this case, as in a stage unit according to claim 2, the plurality of fiducial marks may be at least three fiducial marks each of which is arranged in the

vicinity of one of vertex positions of a polygon, including a center of the substrate holding member. In such a case, the center of the substrate holding member lies within the area of the polygon surrounded by the fiducial marks, therefore, in the case of obtaining the center of the substrate holding member based on the measurement results of the position of the fiducial marks, the central point corresponds, so to speak, to the interpolation point of the fiducial mark positions. Accordingly, by performing a predetermined calculation based on the positional information on or about the fiducial marks, a holding member coordinate system of which origin is the center of the substrate holding member can be obtained with a sufficient level of reliability.

[0015] In the stage unit according to claim 1, as in a stage unit according to claim 3, the plurality of fiducial marks may include a first fiducial mark and a second fiducial mark (Mh, Mi), which are arranged on a straight line passing through a center of the substrate holding member and on opposite sides with respect to the center. In such a case, since the first fiducial mark and the second fiducial mark are arranged on a straight line passing through the center of the substrate holding member on opposite sides with respect to the center, the interval between both fiducial marks can be about the diameter length of the substrate holding member, thereby making it

possible to relax the limitations on the measurement span, and consequently to improve the measurement accuracy. In addition, since the two fiducial marks are symmetric with respect to the center of the substrate holding member, it is possible, for example, to easily calculate the center coordinate and the rotational angle of the substrate holding member.

[0016] In the stage unit according to claims 1 to 3, each of the fiducial marks may be formed directly on the substrate stage. However, as in a stage unit according to claim 4, the stage unit may further comprise: a plurality of fiducial mark plates (FMa to FMd; FMa' to FMd') arranged on a periphery of the substrate holding member on the substrate stage; wherein at least one of the fiducial marks is formed on each of the fiducial mark plates.

[0017] According to the invention according to claim 5, there is provided an exposure apparatus which exposes a substrate (W1, W2) with an energy beam (IL) and forms a predetermined pattern on the substrate, the exposure apparatus comprising: a substrate stage (WST1, WST2) which moves two-dimensionally; a substrate holding member (H1, H2) which is mounted on the substrate stage and which holds the substrate; a plurality of fiducial mark plates (FMa to FMd; FMa' to FMd') on which a plurality of fiducial marks are dispersedly arranged with respect to each of measurement sequences using the fiducial mark plates, the

fiducial marks being arranged on a periphery of the substrate holding member on the substrate stage so that a positional relationship between each of the fiducial marks and the substrate holding member is constant; a mark detection system (24a, 24b) which detects marks located on the substrate stage; and a control unit (90), which performs various types of measurement sequences each including a detection operation for detecting at least one of the plurality of fiducial marks using the mark detection system.

[0018] With this exposure apparatus, a plurality of fiducial mark plates on which a plurality of fiducial marks are arranged, with respect to each of measurement sequences using the fiducial mark plates, on the periphery of the substrate holding member so that the positional relationship between each fiducial mark and the substrate holding member is constant. This allows the fiducial mark plates to be arranged on even a small space on the substrate stage. Furthermore, since the control unit performs various types of measurement sequences each of which includes the detection operation for detecting at least one of the pluralities of fiducial marks by using the mark detection system, the performance related to measurement can be maintained. Accordingly, it becomes possible to downsize the substrate stage, and in turn, to reduce the footprint of the apparatus, while maintaining

its measurement performance.

[0019] In this case, in a case that the exposure apparatus further comprises, as in an exposure apparatus according to claim 6, a position measurement unit which manages a position of the substrate stage on an orthogonal coordinate system, the plurality of fiducial mark plates may include a first mark plate on which a plurality of fiducial marks are arranged along a first axis direction on the orthogonal coordinate system, the first mark plate being an elongated plate extending in the first axis direction, and a second mark plate on which a plurality of fiducial marks are arranged along a second axis direction orthogonal to the first axis direction, the second mark being an elongated plate extending in the second axis direction.

[0020] In this case, as in an exposure apparatus according to claim 7, in a case that the exposure apparatus further comprises: a mask stage (RST) which holds a mask (R) on which the pattern is formed; a drive unit which synchronously moves the mask stage and the substrate stage along the second axis direction; and a pair of mask-mark detection systems (41, 42) which measure at least one pair of mask marks formed on both sides of the pattern on the mask in the first axis direction; wherein a length of the first mark plate in the first axis direction may substantially correspond to a distance between the pair of

mask marks, and a length of the first mark plate in the second axis direction may be slightly greater than a length required to form the fiducial marks. In such a case, it becomes possible to form a pair of fiducial marks which can be measured at the same time with the pair of mask marks detected with the pair of mask-mark detection systems on the first mark plate.

[0021] In the exposure apparatus according to claim 6, as in an exposure apparatus according to claim 8, in a case that the exposure apparatus further comprises: a mask stage which holds a mask having the pattern formed thereon; a drive unit which synchronously moves the mask stage and the substrate stage along the second axis direction; a mask side position measurement unit which measures a position of the mask stage; and a mask-mark detection system which measures a plurality of pairs of mask marks formed on both sides of the pattern on the mask in the first axis direction; wherein a length of the second mark plate in the second axis direction may substantially correspond to a length of the pattern in the second axis direction, and a length of the second mark plate in the first axis direction may be slightly greater than a length required to form the fiducial marks. In such a case, it is possible to form, on the second fiducial mark plate, a fiducial mark usable for scaling adjustment between the mask side position measurement unit and the position measurement unit which

measures the position of the substrate stage using one of the mask-mark detection systems.

[0022] According to the invention according to claim 9, there is provided an exposure apparatus which exposes a substrate (W1, W2) with an energy beam (IL) and which forms a predetermined pattern on the substrate, the exposure apparatus comprising: a substrate stage (WST1, WST2) which moves two-dimensionally; a position measurement unit (16, 18, 44, 46, 48) which measures a position of the substrate stage; a substrate holding member (H1, H2) which is mounted on the substrate stage and which holds the substrate; at least three fiducial marks (Ma1 to Md) each of which is arranged in the vicinity of one of vertex positions of a polygon containing a center of the substrate holding member, and which are arranged on the substrate stage so that a positional relationship between each of the fiducial marks and the substrate holding member is constant; a mark detection system (24a, 24b) which detects marks located on the substrate stage and including the fiducial marks; and a control unit (90) which performs various types of measurement sequences each including a detection operation for detecting one fiducial mark or a plurality of fiducial marks among the at least three fiducial marks using the mark detection system and the position measurement unit.

[0023] With this exposure apparatus, since each of the fiducial marks is arranged in the vicinity of one of

vertexes of the polygon, the interval (distance) between the fiducial marks can be sufficiently large, and limitations on the measurement span can be relaxed, allowing the measurement accuracy to be improved. In addition, the center of the substrate holding member lies within an area of the polygon surrounded by the fiducial marks, therefore, in the case of obtaining the center of the substrate holding member based on the measurement results of the position of the fiducial marks, the central point corresponds, so to speak, to the interpolation point of the fiducial mark positions. Accordingly, the control unit can, for example, detect the positional information about each fiducial mark arranged on the substrate stage by using the mark detection system and the position measurement; and in the control unit, by performing a predetermined calculation based on the positional information, it is possible to obtain the holding member coordinate system which origin is the center of the substrate holding member with a level of reliability sufficient to some extent. Furthermore, the control unit obtains the positional information about the alignment marks existing within the polygon on the substrate by using the mark detection system and the position measurement unit on (based on) an arbitrary coordinate system, such as the stage coordinate system, and converts the information to the positional information on the holding member coordinate

system. This allows the fiducial marks to be re-measured on a new coordinate system, even in the case when the position of the substrate stage cannot be managed temporarily, and based on the measurement results and the positional information on the holding member coordinate system, the positional information about the alignment marks can be obtained with high reliability on the new coordinate system. Accordingly, for similar reasons explained earlier, it becomes possible to control the position of the substrate with good accuracy at all times, without increasing the size of the substrate stage and the footprint of the apparatus.

[0024] In this case, each of the fiducial marks may be formed directly on the substrate stage. However, for example, as in an exposure apparatus according to claim 10, the exposure apparatus may further comprise a plurality of fiducial mark plates on each of which at least one of the fiducial marks is formed, the fiducial mark plates being arranged on a periphery of the substrate holding member on the substrate stage.

[0025] In this case, as in an exposure apparatus according to claim 11, the at least three fiducial marks may be arranged on the plurality of fiducial mark plates, dispersed per each of measurement sequences using the at least three fiducial marks respectively. In such a case, by dispersing the marks, which would be otherwise normally

located in large numbers on the fiducial mark plate, per the measurement sequences therefor respectively, the fiducial mark plates can each be downsized while maintaining its functions, and as a consequence, the substrate stage on which the fiducial mark plates are arranged and the whole exposure apparatus can be downsized.

[0026] In the exposure apparatus according to claims 10 and 11, as in an exposure apparatus according to claim 12, a position of the substrate stage may be managed by the position measurement unit on an orthogonal coordinate system; and the plurality of fiducial mark plates may include a first mark plate on which a plurality of fiducial marks are arranged along a first axis direction on the orthogonal axis system, the first mark plate being an elongated plate extending in the first axis direction, and a second mark plate on which a plurality of fiducial marks are arranged along a second axis direction orthogonal to the first axis direction, the second mark plate being an elongate plate extending in the second axis direction. In such a case, by dispersing the fiducial marks existing in large numbers according to the measurement sequences therefor respectively, the fiducial mark plates can each be downsized while maintaining the performance, and as a consequence, the substrate stage on which the fiducial mark plates are arranged can be downsized.

[0027] In addition, for example, with a scanning type

exposure apparatus, in a case that the first axis direction is the non-scanning direction of the substrate, by the first mark plate having approximately the size of a shot area on the substrate in this direction and a small size in the scanning direction, it is possible to form fiducial marks on the fiducial mark plate which can be measured at the same time with both eyes with a pair of mask-mark detection system constructing a twin lens which measures the mask alignment marks formed on both edges of the mask. On the other hand, in a case that the second axis direction is the scanning direction, by the second mask plate having approximately the size of the shot area in this direction and a small size in the non-scanning direction, it is possible to form fiducial marks, on the fiducial mark plate, usable for scaling adjustment of the interferometer which measures the position of the mask stage and the interferometer which measures the position of the substrate stage, the scaling being performed using a single lens of the mask-mark detection system.

[0028] In the exposure apparatus according to claim 9, as in an exposure apparatus according to claim 13, each of the at least three fiducial marks may be formed in the substrate holding member.

[0029] According to the invention according to claim 14, there is provided an exposure apparatus which exposes a substrate (W1, W2) with an energy beam (IL) and forms a

predetermined pattern on the substrate, the exposure apparatus comprising: a substrate stage (WST1, WST2) which moves two-dimensionally; a position measurement unit (16, 18, 44, 46, 48) which measures a position of the substrate stage; a substrate holding member (H1, H2) which is mounted on the substrate stage and which holds the substrate; at least two fiducial marks (Mh, Mi) including a first fiducial mark and a second fiducial mark which are arranged on a straight line passing through a center of the substrate holding member and on opposite sides with respect to the center, and are which are arranged on the substrate stage so that a positional relationship between each of the fiducial marks and the substrate holding member is constant; a mark detection system (24a, 24b) which detects marks located on the substrate stage including the at least two fiducial marks; and a control unit (90) which performs various types of measurement sequences each including a detection operation to detect one fiducial mark or a plurality of fiducial marks among the at least two fiducial marks, using the mark detection system and the position measurement unit.

[0030] According to this exposure apparatus, since the first fiducial mark and the second fiducial mark are arranged on a straight line passing through the center of the substrate holding member on opposite sides with respect to the center, the interval between both fiducial marks can

be about the diameter of the substrate holding member, therefore, limitations on the measurement span can be relaxed, allowing the measurement accuracy to be improved. In addition, the center of the substrate holding member lays or is present on the straight line connecting both fiducial marks. Therefore, in a case that the center of the substrate holding member is obtained based on the measurement results of the position of the fiducial marks, the central point corresponds, so to speak, to the interpolation point of the fiducial mark positions. Accordingly, the control unit can, for example, detect the positional information about each of the fiducial marks arranged on the substrate stage by using the mark detection system and the position measurement, and by performing a predetermined calculation based on the positional information, thereby making it possible to obtain the holding member coordinate system of which origin is the center of the substrate holding member, with a level of reliability sufficient to some extent. Furthermore, the control unit obtains the positional information about the alignment marks lying within the polygon on the substrate by using the mark detection system and the position measurement unit on an arbitrary coordinate system, such as the stage coordinate system, and control unit converts the information to the positional information on the holding member coordinate system. This allows the fiducial marks

to be re-measured on a new coordinate system, even in the case when the position of the substrate stage cannot be managed temporarily, and based on the measurement results and the positional information on the holding member coordinate system, the positional information about the alignment marks can be obtained with high reliability on the new coordinate system. Accordingly, for similar reasons explained earlier, it is possible to control or manage the position of the substrate with good accuracy at all times, without increasing the size of the substrate stage and the footprint of the apparatus. In this case, since the two fiducial marks are symmetrical with respect to the center of the substrate holding member, it is possible, for example, to easily calculate the center coordinates and the rotational angle of the substrate holding member.

[0031] In this case, as in an exposure apparatus according to claim 15, the exposure apparatus may further comprise a plurality of fiducial mark plates which are arranged on a periphery of the substrate holding member on the substrate stage, and on each of which one of the at least two fiducial marks is formed.

[0032] In this case, as in an exposure apparatus according to claim 16, the at least two fiducial marks may be arranged on a plurality of fiducial mark plates and dispersed with respect to each of measurement sequences

using the fiducial marks.

[0033] In the exposure apparatus according to claims 15 and 16, as in an exposure apparatus according to claim 17, a position of the substrate stage may be managed by the position measurement unit on an orthogonal coordinate system; and the plurality of fiducial mark plates may include a first mark plate on which a plurality of fiducial marks including the first fiducial mark are arranged along a first axis direction on the orthogonal axis system, the first mark plate being an elongated plate extending in the first axis direction, and a second mark plate on which a plurality of fiducial marks including the second fiducial mark are arranged along a second axis direction orthogonal to the first axis direction, the second mark plate being an elongated plate extending in the second axis direction.

[0034] In the exposure apparatus according to claim 14, as in an exposure apparatus according to claim 18, each of the at least two fiducial marks may be formed on the substrate holding member.

[0035] In addition, in the exposure apparatus according to each of claims 14, 15, 16 and 18, as in an exposure apparatus according to claim 19, a position of the substrate stage may be managed by the position measurement unit on an orthogonal coordinate system; and the straight line connecting the first fiducial mark and the second fiducial mark may be tilted at an angle of approximately 45

degrees with respect to both coordinate axes of the orthogonal coordinate system.

[0036] In such a case, since the straight line which connects the first fiducial mark and second fiducial mark has a tilt at an angle of approximately 45 degrees with respect to the coordinate axes of the orthogonal coordinate system, it is possible to measure the position of the mark with the accuracy of the same level in the direction of both axes in the orthogonal coordinate system.

[0037] In the detection operations of the fiducial marks with the exposure apparatus according to the present invention, the positional information about the fiducial marks (for example, coordinate values on the orthogonal coordinate system which sets the movement of the substrate stage) does not necessarily have to be detected. For example, the fiducial marks may only be used for detection of the positional information (including the relative positional relationship with the fiducial marks) of marks formed on the mask or the mask stage or the like, or for detecting the optical properties or characteristics (such as projection magnification) of the projection optical system. For example, the projection magnification of the projection optical system can be easily obtained by detecting the relative positional relationship between a plurality of marks which are formed on the mask or the mask stage and a plurality of fiducial marks which correspond to

these marks and which are formed on the substrate stage, or by detecting the positional relationship between a plurality of marks on a side of the mask stage (mask stage side) and the positional relationship between a plurality of fiducial marks on a side of the substrate stage (substrate stage side). The correspondence of the mask coordinate system and the substrate coordinate system can also be obtained by detecting the relative positional relationship between a plurality of marks which are formed on the mask or the mask stage at a predetermined interval in a predetermined direction and a plurality of fiducial marks which correspond to these marks and which are formed on the substrate stage.

[0038] Furthermore, the fiducial marks on the substrate stage in the present invention refers not only to fiducial marks which are formed directly on the substrate stage and fiducial marks which are formed on mark plates fixed on the substrate stage, but also includes fiducial marks which are formed on the substrate holding member or on the mark plates fixed on the substrate holding member.

[0039]

[EMBODIMENTS OF THE INVENTION]

An embodiment of the present invention will be described below, with reference to FIGS. 1 to 4.

[0040] FIG. 1 shows a schematic construction or arrangement of an exposure apparatus 10 according to the

present invention. The exposure apparatus 10 is a scanning exposure apparatus based on the so-called step-and-scan system.

[0041] The exposure apparatus 10 includes: an illumination system 20 which illuminates the reticle R serving as a mask from above with an exposure light IL; a reticle drive system which drives the reticle R mainly in the scanning direction (in this case, the Y-axis direction which is the direction perpendicular to the sheet surface of FIG. 1); a projection optical system PL which is arranged below the reticle R; a stage unit which is arranged below the projection optical system PL and which includes wafer stages WST1 and WST2, serving as substrate stages, the wafer stages WST1 and WST2 moving independently in two dimensional directions and respectively holding wafers W1 and W2 serving as substrates; a control system which controls each of the above-mentioned systems and units, etc,; and the like.

[0042] As is disclosed, for example, in Japanese Patent Application Laid-open No. 10-112433, Japanese Patent Application Laid-open No. 06-349701 and U.S. Patent No. 5,534,970 corresponding thereto, the illumination system 20 is constructed to include: a light source; an illuminance uniformity optical system which includes an optical integrator; a relay lens; a variable ND filter; a reticle blind; a dichroic mirror; and the like (all are omitted in

the drawings). As the optical integrator, a fly-eye lens, a rod integrator (an internal reflection type integrator), a diffraction optical element or the like can be used.

[0043] In the illumination system 20, an exposure light IL serving as an energy beam illuminates, with uniform illuminance, an illumination area on the reticle R in which the circuit pattern is formed and which is defined to have a slit shape by the reticle blind. As the exposure light IL, in this embodiment, a far ultraviolet light such as the KrF excimer laser beam (wavelength: 248 nm) or the ArF excimer laser beam (wavelength: 193 nm), or a vacuum ultraviolet light such as the F_2 laser beam (wavelength: 157 nm) is to be used. It is also possible to use, as the exposure light IL, the emission line (such as the g-line or the i-line) in the ultraviolet light region from an ultra-high pressure mercury lamp.

[0044] The reticle drive system includes: a reticle stage RST which holds the reticle R and which is capable of moving within a XY two-dimensional plane along the reticle base plate 25 shown in FIG. 1; a reticle drive portion which includes linear motors and the like (not shown in the drawings) driving the reticle stage RST; and a reticle interferometer system 28 which controls the position of the reticle stage RST, as a mask-side measuring device.

[0045] More specifically, the reticle stage RST is, in actual, supported by air levitation on the reticle base

plate 25 via a non-contact bearing (not shown in the drawings) such as a vacuum pre-load aerostatic bearing unit; the reticle stage RST is constructed of a reticle coarse movement stage which is driven with predetermined strokes in the Y-axis direction as the scanning direction by a linear motor (not shown in the drawings) and a reticle fine movement stage which is driven with respect to the reticle coarse movement stage in the X-axis, Y-axis, and θz direction (rotational direction around the Z-axis) by a drive mechanism constructed of a voice coil motor or the like. On the reticle fine movement stage, the reticle R is held by suction via electrostatic chucking or vacuum chucking (not shown in the drawings). Although it is omitted in the drawings, as is disclosed, for example, in the Japanese Patent Application Laid-open No. 08-63231 and U.S. Patent No. 6,246,204 corresponding thereto, the reaction force generated by the movement of the reticle coarse movement stage is excluded or eliminated by relatively moving the mover and stator of the linear motor which drives the reticle coarse movement stage in the opposite direction with respect to the reticle base plate 25.

[0046] As described above, the reticle stage RST is actually constructed of two stages, however, for the sake of convenience, the reticle stage RST will hereinafter be described as a single stage which is finely driven in the

X-axis and Y-axis direction, finely rotated in the θz direction, and scanned in the Y-axis direction by a reticle drive portion (not shown in the drawings).

[0047] On the edge portion on the -side (-X side) in the X-axis direction (+X side) on the reticle stage RST, as is shown in FIG. 2, a parallel plate movable mirror 39 made of the same material as the reticle stage RST (such as ceramic) extends in the Y-axis direction; and on the surface of the edge portion on the-side (-X side) in the X-axis direction of the movable mirror 39, a reflection surface is formed by mirror polishing. An interferometer which constructs the interferometer system 28 shown in FIG. 1 and which is referred to as a length measuring axis BI6X irradiates an interferometer beam onto the reflection surface of the movable mirror 39. The interferometer receives the reflected light and measures relative displacement thereof with respect to a reference surface to thereby measure the position of the reticle stage RST. This interferometer having the length measuring axis BI6X actually has two interferometer optical axes which are capable of performing measurements individually, and is capable of measuring the position of the RST stage in the X-axis direction as well as the yawing amount (θz rotational amount). The interferometer having the length measuring axis BI6X is used to control the rotation of the reticle stage RST in the direction to cancel out the

relative rotation (rotational error) between the reticle and the wafer and to perform the alignment of the reticle and wafer in the X direction, based on the information about yawing and X position of the wafer stage WST1 (or WST2) provided from the interferometer 16 (or 18) (refer to FIG. 3) arranged on the wafer stage side and having the length measuring axis BI1X (or BI2X). The interferometer 16 (or 18) will be described further, later on in the description.

[0048] On the other hand, a pair of corner cube mirrors 35A and 35B are arranged on the -side (front side on the sheet surface of FIG. 1) in the Y-axis direction (-Y side) which is the scanning direction of the reticle stage RST. And onto the corner cube mirrors 35A and 35B, a pair of double path interferometers (not shown in the drawings) irradiate interferometer beams which are shown as length measuring axes BI7Y and BI8Y in FIG. 2. The interferometer beams irradiated onto the corner cube mirrors 35A and 35B are returned onto a reflection surface (not shown in the drawings) arranged on the reticle base plate 25. Further, the reflected lights each reflected off the reflection surface (not shown in the drawings) are retuned along a same optical path and are received by the double path interferometers respectively; and the relative displacement from the reference positions of the respective corner cube mirrors 35A and 35B (the reflection surface on the reticle

base plate 25) are measured. The measurement values of these double path interferometers are supplied to a stage control unit 70 (refer to FIG. 1); and, for example, the stage control unit 70 calculates the position of the reticle stage RST in the Y-axis direction based on the average of the measurement values. The calculation results of the stage control unit 70 are supplied to a main controller 90. The information about the position of the reticle stage RST in the Y-axis direction measured with the double path interferometers is used in order to calculate the relative position of the reticle stage RST with respect to the wafer stage WST1 (or WST2) based on the measurement values of a Y-axis interferometer 46 on the wafer side (refer to FIG. 3) which has a length measuring axis BI2Y, and based on this calculation, to synchronously control the reticle and the wafer in the scanning direction (Y-axis direction) upon scanning exposure. The interferometer 46 will also be described further, later on in the description.

[0049] That is, in this embodiment, the interferometer represented by the length measuring axis BI6X and the pair of double path interferometers represented by the length measuring axes BI7Y and BI8Y constructs the reticle interferometer system 28 as shown in FIG. 1.

[0050] Also, the material of the glass substrate structuring the reticle R needs to be different depending

on the light source used. For example, in the case of using a vacuum ultraviolet light such as the F_2 laser light as the light source, the glass substrate needs to be made of materials such as fluorite, or fluoride crystals such as magnesium fluoride or lithium fluoride, or synthetic quartz which has a hydroxyl concentration of not more than 100 ppm and contains fluorine (fluorine doped quartz). Or, in the case of using the ArF excimer laser or the KrF excimer laser as the light source, other than the materials referred to above, it is possible to use synthetic quartz.

[0051] In this embodiment, as the projection optical system PL, a refraction optical system which is constructed of a plurality of lens elements having a common optical axis in the Z-axis direction and is double telecentric (telecentric on both sides) with a predetermined reduction magnification such as 1/5 or 1/4 is used. Therefore, the movement velocity of the wafer stage in the scanning direction upon scanning exposure based on the step-and-scan system is 1/5 or 1/4 of the movement velocity of the reticle stage.

[0052] As is shown in FIG. 1, the stage unit includes: two wafer stages WST1 and WST2 which are arranged above the base plate 12; a stage drive system which drives these wafer stages WST1 and WST2; and an interferometer system serving as a position measurement unit which measures the position of the wafer stages WST1 and WST2. The wafer

stages WST1 and WST2 are supported by air levitation via a non-contact bearing (not shown in the drawings) such as a vacuum pre-load aerostatic bearing unit (hereinafter referred to as an "air pad") above the base plate 12 via a predetermined clearance. Further, the wafer stages WST1 and WST2 are structured so that they can be driven independently in two-dimensional directions by the stage drive system, in the X-axis direction (the left and right direction on the sheet surface of FIG. 1) which is the first axis direction and the Y-axis direction (the orthogonal direction orthogonal to the sheet surface of FIG. 1) which is the second axis direction.

[0053] More particularly, on the bottom surface of the wafer stages WST1 and WST2, a plurality of air pads (not shown in the drawings) are arranged, and due to the balance of the air exhaustion force and the vacuum pre-load force of the air pads the wafer stages WST1 and WST2 are supported by air levitation above the base plate 12 in a state that, for example, a space of around several μm is maintained.

[0054] On the base plate 12, as shown in the planar view in FIG. 3, X-axis linear guides (for example, a guide constructed of a magnetic pole unit which has a permanent magnet) 86 and 87 which extend in the X-axis direction are arranged in a pair at a predetermined interval along the Y-axis direction. Above these X-axis linear guides 86 and

87, two sliders each of which is capable of moving along the X-axis linear guides, namely sliders 82 and 84 and sliders 83 and 85, are supported by air levitation via air pads respectively (not shown in the drawings), for example, via a clearance of around several μm. The sectional shape of the four sliders 82, 84, 83, and 85 is the shape of the letter U upside down as if the X-axis linear guides 86 and 87 were enclosed or surrounded from above and from the sides, and the inner portion of each of the four sliders 82, 84, 83, and 85 contains an armature coil. That is, in this embodiment, the sliders (armature units) 82 and 84 and the X-axis linear guide 86 respectively construct the moving coil type X-axis linear motors. Likewise, the sliders (armature units) 83 and 85 and the X-axis linear guide 87 respectively construct the moving coil type X-axis linear motors. In the following, the four X-axis linear motors which are mentioned above will each be referred to as X-axis linear motor 82, X-axis linear motor 84, X-axis linear motor 83, and X-axis linear motor 85 as appropriate, using the same reference numbers as the sliders 82, 84, 83, and 85 which construct the movers of the respective X-axis linear motors.

[0055] Among the four X-axis linear motors (sliders) 82 to 85, two of them, namely the X-axis linear motors 82 and 83, are respectively fixed on one end and the other end in the longitudinal direction of the Y-axis linear guide

(which is, for example, constructed of an armature unit having an armature coil built in) 80 extending in the Y-axis direction. In addition, the remaining two X-axis linear motors 84 and 85 are fixed on one end and the other end to a similar Y-axis linear guide 81 which also extends in the Y-axis direction. Accordingly, the Y-axis linear guides 80 and 81 are respectively driven along the X-axis by the X-axis linear motors 82, 83, 84, and 85 in pairs.

[0056] On the bottom portion of the wafer stage WST1, a magnetic pole unit (not shown in the drawings) which has a permanent magnet is arranged. This magnetic pole unit and the Y-axis linear guide 80 as one of the Y-axis linear guides construct the moving magnet type Y-axis linear motor which drives the wafer stage WST1 in the Y-axis direction. Furthermore, on the bottom portion of the wafer stage WST2, a magnetic pole unit (not shown in the drawings) which has a permanent magnet is arranged. This magnetic pole unit and the Y-axis linear guide 81 as the other Y-axis linear guide construct the moving magnet type Y-axis linear motor which drives the wafer stage WST2 in the Y-axis direction. In the following, these Y-axis linear motors will be referred to as Y-axis linear motor 80 and Y-axis linear motor 81 as appropriate, using the same reference numbers as the linear guides 80 and 81 which construct the stators of the respective Y-axis linear motors.

[0057] In addition, in the embodiment, each of the X-

axis linear motors 82 to 85 and the Y-axis linear motors 80 and 81 is controlled by the stage control unit 70, which is shown in FIG. 1.

[0058] Also, the yawing of the wafer stage WST1 (or WST2) can be controlled by slightly varying the thrusts generated by the pair of X-axis linear motors 82 and 83 (or 84 and 85) respectively.

[0059] Referring back to FIG. 1, a wafer holder H1 serving as a substrate holding member is arranged on the wafer stage WST1. On the upper surface of the wafer holder H1, as is shown in FIG. 4, a plurality of projected portions 72 which are concentric circles having different radiuses are formed; and through the suction holes (not shown in the drawings), which are arranged on the bottom surface of the groove portions formed between these projected portions 72, the wafer W1 is held by suction on the wafer holder H1 by the vacuum chucking force of the vacuum pump (not shown in the drawings).

[0060] And, as also shown in FIG. 4, at predetermined positions on a peripheral portion of the wafer holder H1 (more particularly, in the vicinity of the corners of a squarish shape formed outside the wafer holder H1), four fiducial mark plates FMa, FMb, FMc, and FMd on which fiducial marks are respectively formed are arranged so that the surface of these plates and the surface of the wafer W1 are at the same height. These fiducial mark plates FMa,

FMb, FMc, and FMd are each integrally fixed to the wafer holder H1 via the fiducial mark plate holding portions 33a, 33b, 33c, and 33d. That is, the positional relationship between the fiducial mark plates FMa, FMb, FMc, and FMd and the wafer holder HI is constant.

[0061] On the upper surface of the fiducial mark plate FMa, as is shown in FIG. 4, fiducial marks Ma1 and Ma2 are formed in a pair in the X-axis direction at a predetermined interval. These fiducial marks Ma1 and Ma2 are arranged at a position at which both of the marks can be measured at the same time with both eyes using a pair of RA microscopes 41 and 42 (refer to FIG. 1) which constructs a twin lens (to be described later on). The fiducial mark plate FMa on which the fiducial marks Ma1 and Ma2 are formed has a rectangular shape in a planar view, and a size of the plate in the X-axis direction is substantially same as the size of the shot area on the wafer W1 and a size of the plate in the Y-axis direction is sufficient to an extent that the fiducial marks can be formed thereon.

[0062] Furthermore, on the fiducial mark plate FMb, three fiducial marks Mb1, Mb2, and Mb3 are formed in the Y-axis direction at a predetermined interval. These fiducial marks Mb1, Mb2, and Mb3 are for the so-called scaling measurement which is performed upon the so-called baseline measurement between interferometers which respectively measure the position of the reticle stage RST and wafer

stage WST1, in other words, these are marks used for alignment confirmation during relative scanning operation. The fiducial mark plate FMb on which these fiducial marks Mb1 Mb2, and Mb3 are formed has a rectangular shape in a planar view, and a size of the plate in the Y-axis direction is substantially same as the size of the shot area on the wafer W1 and a size of the plate in the X-axis direction side is sufficient to an extent that the fiducial marks can be formed thereon.

[0063] In addition, on the remaining fiducial mark plates FMc and FMd, the fiducial marks Mc and Md are respectively formed. These fiducial marks Mc and Md are used in cases when the center of the wafer holder H1 and the rotation of the wafer holder H1, etc. are to be calculated by the least squares method. Various measurement methods using each of the fiducial marks formed on the respective fiducial mark plates referred to above will be described later on in the description.

[0064] In this case, since the fiducial mark plates FMa, FMb, FMc, and FMd are arranged so that they are located on the corners of a squarish shape (substantially a square) which includes the center of the wafer holder H1, the entire surface of the wafer W1 is substantially enclosed or included in an area within the squarish shape (an area EA surrounded with the dotted line in FIG. 4). The reason for this will be explained later in the description.

[0065] On the upper surface of the wafer stage WST1, an X movable mirror 96a, which has a reflection surface perpendicular to the X-axis, is arranged on one end in the X-axis direction (the end on the -X side) extending in the Y-axis direction. Further, a Y movable mirror 96b, which has a reflection surface perpendicular to the Y-axis, is arranged on one end in the Y-axis direction (the end on the +Y side) extending in the X-axis direction. Onto each of the reflection surfaces of the movable mirrors 96a and 96b, as shown in FIG. 2 and FIG. 3, interferometer beams (length measuring beams) from interferometers which have a predetermined length measuring axis and construct an interferometer system (which will be described later) are projected. By detecting or photo-detecting the reflected lights by the respective interferometers, it is possible to measure the displacement of the reflection surface of each movable mirror from the reference position (normally, the reference surface is set by arranging a fixed mirror on the side surface of the projection optical system PL or the alignment system) to thereby make it possible to measure the two-dimensional position of the wafer stage WST1.

[0066] Although the two wafer stages WST1 and WST2 are symmetrical (bilaterally symmetrical), the structure of the wafer stage WST2 as the other wafer stage is similar to that of the wafer stage WST1 described above.

[0067] Namely, as shown in FIG. 1, a wafer W2 is vacuum

chucked via a vacuum chuck (not shown in the drawings) on the wafer stage WST2 via a wafer holder H2 which serves as a substrate holding member. The wafer holder H2 basically has a structure similar to that of the above-described wafer holder H1, and as shown in FIG. 2 and FIG. 3, four fiducial mark plates FMa', FMb', FMc', and FMd' are arranged in a predetermined positional relationship on a peripheral portion of the wafer holder H2, to be more specific, each at a position on one of the corners of the squarish shape having substantially a perfect square; and the fiducial mark plates are each integrally fixed to the wafer holder H2 via the fiducial mark plate holding portions. These fiducial mark plates FMa', FMb', FMc', and FMd' are arranged so that their upper surface is set at the same height as of the surface of the wafer W2 mounted on the wafer holder H2. Furthermore, on the upper surface of the wafer stage WST2, movable mirrors 96c and 96d are each arranged to extend on the wafer stage WST2. Onto these movable mirrors 96c and 96d, as shown in FIG. 2, interferometer beams from interferometers which have a predetermined length measuring axis and which construct an interferometer system (which will be described later) are projected. By detecting the reflected lights by the respective interferometers, the two-dimensional position of the wafer stage WST2 is measured.

[0068] Also, as shown in FIG. 2 and FIG. 3, the fiducial

mark plates on the wafer stage WST2 which correspond to the fiducial mark plates on the wafer stage WST1 are designated with a symbol " ' " added to the reference number used for the wafer stage WST1. Therefore, hereinafter in the description, the fiducial marks will also be designated with a symbol " ' ", likewise with the fiducial mark plates for the sake of convenience.

[0069] Referring back to FIG. 1, on the both sides of the projection optical system PL in the X-axis direction, alignment systems 24a and 24b which are based on the off-axis system and have the same functions are arranged at positions equally apart from the optical axis of the projection optical system PL (coincides with the projection center of the reticle pattern image). In this embodiment, as the alignment systems 24a and 24b, FIA (Filed Image Alignment) system microscopes which is based on the image processing system are used, wherein a broadband detection light flux which does not expose the resist on the wafer is irradiated onto a target mark so that an image is formed from the light reflected off the subject mark on the photodetection (photo-receiving) surface, and this image and an index image (not shown in The drawings) are picked up with a pick-up device (CCD) or the like, and pick-up signals thereof are outputted. Based on the output of the alignment systems 24a and 24b, it is possible to measure the position of the fiducial marks on the fiducial mark

plates as well as the alignment marks on the wafers in the XY two-dimensional directions.

[0070] Other than the FIA system, it is possible, for example, to use a single or a combination of alignment sensors as the alignment system 24a and 24b, so that a coherent detection light is irradiated onto the target mark and a scattered light or diffraction light generated from the mark is detected, or two diffraction lights (for example, lights of the same order) generated from the target mark made to interfere with each other are detected.

[0071] In the embodiment, the alignment system 24a is used to measure the position of the alignment marks on the wafer W1 held on the wafer stage WST1 and the position of the fiducial marks formed on each of the fiducial mark plates on the wafer stage WST1 and the like. Further, the alignment system 24b is used to measure the position of the alignment marks on the wafer W2 held on the wafer stage WST2 and the position of the fiducial marks formed on each of the fiducial mark plates on the wafer stage WST2, and the like.

[0072] The information from the alignment systems 24a and 24d is converted from analog to digital by the alignment control unit 60, and the digitalized waveform signals are processed to detect the positions of the marks (mark positions), namely the positional information of the target marks subject to detection, with the index center of

the respective alignment systems 24a and 24b being as the reference. The detection results from the alignment control unit 60 is sent to the main controller 90, and in accordance with the results the main controller 90 gives instructions to the stage control unit 70 on synchronous positional correction during exposure and the like.

[0073] Next, an explanation will be given, with reference to FIGS. 1 to 4, about the structure of the interferometer system which controls the position of the wafer stage WST1 and WST2 and the like.

[0074] As shown in FIGS. 1 to 4, the movable mirror 96a is arranged on one side of the X-axis direction on the upper surface of the wafer stage WST1 along the first axis (X-axis) which passes through the projection center (optical axis AX) of the projection optical system PL as well as each detection center (optical axes SXa and SXb) of the alignment systems 24a and 24b. The interferometer beam from the X-axis interferometer 16, referred to as the length measuring axis BI1X in FIG. 1, is irradiated onto the movable mirror 96a, and similarly, the interferometer beam from the X-axis interferometer 18, referred to as the length measuring axis BI2X in FIG. 1, is irradiated onto the movable mirror 96c, which is also arranged along the first axis on the upper surface of the wafer stage WST2, on the other side of the X-axis direction. Further, the interferometers 16 and 18 measure the relative displacement

from the reference position of the respective reflection surfaces by receiving or photo-detecting the reflected lights, to thereby measure the position of the wafer stages WST1 and WST2 in the X-axis direction. As is shown in FIG. 2, each of the interferometers 16 and 18 is a three axes interferometer having three optical axes, and is capable of performing measurement of the rotational amount around the Y-axis (rolling amount) and the rotational amount around the Z-axis (yawing amount), in addition to the measurement of the position of the wafer stages WST1 and WST2 in the X-axis direction. The output values of the respective optical axes can be measured independently. In the foregoing description, the wafer stages WST1 and WST2 are described as if each of the wafer stages WST1 and WST1 is a single stage. However, each of the wafer stages WST1 and WST2 is actually provided with a stage main body which is driven by the Y-axis motors 80 and 81 and a wafer table placed on an upper portion of the stage main body via a Z leveling drive mechanism (not shown in the drawings). Further, the movable mirrors are respectively fixed to the wafer tables. Accordingly, upon tilt control, the interferometer 16 and 18 and the like can fully monitor the drive amount of the wafer table on which the wafer W is mounted.

[0075] As described above, each of the wafer stages WST1 and WST2 is constructed of a plurality of parts such as the

stage main body and the wafer table. However, in the following, for the sake of convenience on description, the wafer stages WST1 and WST2 will each be described as a single stage which is capable of moving in directions of five degrees of freedom, excluding the rotational direction around the Z-axis (the θz direction). As a matter of course, the wafer stage may be capable of moving in direction of six degrees of freedom, including the θz direction.

[0076] Furthermore, the interferometer beams of the length measuring axis BI1X and the length measuring axis BI2X are each set so as to be irradiated onto the movable mirrors 96a and 96c of the wafer stages WST1 and WST2 at all times, in the entire movement area of the wafer stages WST1 and WST2. Accordingly, the position of the wafer stages WST1 and WST2 in the X-axis direction is controlled based on the measurement values of the length measuring axis BI1X and the length measuring axis BI2X at times such as when exposure is performed using the projection optical system PL and when the alignment systems 24a and 24b are used.

[0077] In addition, in this embodiment, as shown in FIG. 2 and FIG. 3, there are arranged a Y-axis interferometer 46 having the length measuring axis BI2Y which crosses perpendicularly with the X-axis at the projection center of the projection optical system PL, and Y-axis

interferometers 44 and 48 respectively having the length measuring axes BI1Y and BI3Y which respectively cross perpendicularly with the X-axis at the detection center of the respective alignment systems 24a and 24b.

In this case, when the position of the wafer stages WST1 and WST2 in the Y-axis direction upon exposure is to be measured using the projection optical system PL, the measurement values of the interferometer 46 having the length measuring axis BI2Y which passes through the projection center of the projection optical system PL, or in other words, the optical axis AX, are used. When the position of the wafer stage WST1 in the Y-axis direction is to be measured during the usage of the alignment system 24a, the measurement values of the interferometer 44 having the length measuring axis BI1Y which passes through the detection center of the alignment system 24a, or in other words, the optical axis SXa, are used. Further, when the position of the wafer stage WST2 in the Y-axis direction is to be measured during the usage of the alignment system 24b, the measurement values of the interferometer 48 having the length measuring axis BI3Y which passes through the detection center of the alignment system 24b, or in other words, the optical axis SXb, are used.

[0078] Accordingly, due to each of the usage conditions, the length measuring axes of the interferometers in the Y-axis direction stray off (is shifted from) the reflection

surface of the movable mirrors 96b and 96d arranged on the upper surface of the wafer stages WST1 and WST2. However, since at least one length measuring axis, namely the above-described length measuring axes BI1X and BI2X stays within (is not shifted from) the range of the movable mirrors 96a and 96c of the respective wafer stages WST1 and WST2, it is possible to reset the interferometers on the Y side at an appropriate position at which the optical axis of the interferometer to be used comes in and is reflected off the reflection surface.

[0079] As is shown in FIG. 2, each of the interferometers used for measurement of the Y-axis side, 44, 46, and 48 is a double axes interferometer which has two optical axes, and which is capable of performing measurement of the rotational amount around the X-axis (pitching amount), in addition to the measurement of the wafer stages WST1 and WST2 in the Y-axis direction. It is possible to measure the output values of each optical axis independently.

[0080] In this embodiment, a total of five interferometers, that are the two X-axis interferometers 16 and 18 and the three Y-axis interferometers 44, 46 and 48, construct the interferometer system controlling or managing the two-dimensional coordinate positions of the wafer stages WST1 and WST2.

[0081] In addition, in this embodiment, as will be

described later on, while either one of the wafer stages WST1 or WST2 is executing the exposure sequence, the other stage performs wafer exchange or executes the wafer alignment sequence. During these operations, however, the stage control unit 70 controls or manages the movement of the wafer stages WST1 and WST2 in accordance with instructions from the main controller 90 based on the output values of each interferometer, so that both stages do not interfere with each other.

[0082] Furthermore, in the exposure apparatus 10 of the embodiment, as shown in FIG. 1, a pair of reticle alignment microscopes (hereinafter referred to as "RA microscope" for the sake of convenience) 41 and 42 are arranged above the reticle R. These RA microscopes are constructed of a TTR (Through The Reticle) alignment optical system which uses the exposure wavelength to observe the reticle mark RM1 and RM2 on the reticle R and the marks on the fiducial mark plates at the same time via the projection optical system PL. Detection signals from the RA microscopes are sent to the main controller 90 via the alignment control unit 60. In this case, deflection mirrors 31 and 32 are arranged to be freely movable so as to guide the detection lights from the reticle R to the RA microscopes 41 and 42 respectively; and when the exposure sequence is started, each of the deflection mirrors 31 and 32 is withdrawn or retracted by a mirror drive unit (not shown in the drawings) based on

instructions from the main controller 90. Furthermore, details of the structure similar to the RA microscopes 41 and 42 are disclosed, for example, in the Japanese Patent Application Laid-open No. 07-176468 (and U.S. Patent No. 5,646,413 corresponding thereto), etc.

[0083] In addition, although it is omitted in the drawings, automatic focusing/automatic leveling measurement mechanisms (hereinafter referred to as "AF/AL systems") for finding or investigating the focusing position are provided on the projection optical system PL and alignment systems 24a, 24b, respectively. Among these mechanisms, the AF/AL system in the projection optical system PL is provided to detect whether or not the exposure surface of the wafer (W1 or W2) is within the focal depth range of the image plane of the projection optical system PL (whether or not the exposure surface is focused). The reason why this is necessary is because in order that the pattern of the reticle R is transferred accurately onto the wafer (W1 or W2) by scanning exposure, it is necessary that the surface on which the pattern is formed on the reticle R and the exposure surface on the wafer (W1 or W2) are conjugate at all times with respect to the projection optical system PL. In this embodiment, as the AF/AL system, the so-called multiple focal position detection system is used which details are disclosed, for example, in the Japanese Patent Application Laid-open No. 06-283403 (and U.S. Patent No.

5,448,332 corresponding thereto), etc.

[0084] Further, the AF/AL systems provided in the alignment systems have a similar structure as that described above; and by performing positional measurement of the alignment marks when measurement is being performed with the alignment sensors of the alignment systems 24a and 24b while executing the automatic focusing/automatic leveling based on measurement and control by the AF/AL system which are similar that performed during the exposure, it is possible to perform the alignment measurement with high precision.

[0085] The control system of the exposure apparatus 10 is constructed of a microcomputer (or a workstation) and the like, as shown in FIG. 1, and is constructed of the main components which are the main controller 90 serving as the control unit which has overall control over the entire apparatus, the stage control unit 70 which is under the control of the main controller 90, the alignment control unit 60, and the like.

[0086] Next, an explanation will be given about the simultaneous parallel processing performed on the two wafer stages WST1 and WST2 of the exposure apparatus 10 according to this embodiment, focusing on the operations of each of the constitutive parts, section or portion constructing the control system shown in FIG. 1, and focusing on the wafer alignment operation.

[0087] The explanation will be given about a case in which an exposure operation is performed on the wafer W2 on the side of the wafer stage WST2 (wafer stage WST2 side), while an alignment operation is performed in parallel on the wafer W1 on the side of the wafer stage WST1 (wafer stage WST1 side), as shown in FIG. 2. It is to be noted that on a surface of each of the wafers W1 and W2, although it is not shown in the drawing, a large number of shot areas (divided areas) are formed at a predetermined pitch in the X-axis direction and in the Y-axis direction; and that in each of shot areas, a predetermined circuit pattern, and the X-axis wafer marks and the Y-axis wafer marks used for alignment are formed by a semiconductor manufacturing process previously conducted. In the following, each of these wafer marks will be referred to as an "alignment mark" in general.

[0088] (a). First of all, on the wafer stage WST2 side, exposure on the wafer W2 is performed in the following manner. That is, the stage control unit 70 moves the wafer stage WST2 so that the first shot area on the wafer W2 is moved to a starting position for scanning exposure (acceleration starting position), by controlling the X-axis linear motors 84 and 85 and the Y-axis linear motor 81 while monitoring the measurement values of the interferometer 46 which has the length measuring axis BI2Y and the interferometer 18 which has the length measuring

axis BI2X in the interferometer system. This operation is performed by the stage control unit 70 in accordance with the instructions from the main controller 90 based on the alignment results performed in advance, similarly with the alignment operation on the wafer W1, which will be referred to later in the description.

[0089] (b). Next, in the stage control unit 70, relative scanning in the Y-axis direction of the reticle R and the wafer W2 is started, that is, the reticle stage RST and the wafer stage WST2 in the Y-axis direction are started to be scanned relative to each other, according to instructions from the main controller 90. When both the reticle stage RST and the wafer stage WST2 reach their target scanning velocities respectively and arrive at a synchronous state of constant velocity, then the illumination system 20 starts to irradiate the pattern area on the reticle R with the ultraviolet pulse light, thereby starting scanning exposure. The relative scanning described above is performed by the stage control unit 70 which controls the reticle drive portion, the X-axis linear motors 84 and 85 and the Y-axis linear motor 81, while monitoring the measurement values of interferometers 46 and 18 of the above-described interferometer system having the length measuring axes BI2Y and BI2X and the measurement values of the interferometers of the reticle interferometer system 28 having the length measuring axes BI7Y, BI8Y, and BI6X.

[0090] (c). Prior to the starting of the scanning exposure, at a point of time when both stages RST and WST2 reach their target scanning velocities respectively, the main controller 90 instructs a laser control unit (not shown in the drawings) to start pulse emission. The stage control unit 70, however, synchronously controls the movement of predetermined blades of the movable reticle blind within the illumination system 20 via a blind drive unit (not shown in the drawings) and the movement of the reticle stage RST. Therefore, this prevents the ultraviolet pulse light from being irradiated onto an area other than the pattern area on the reticle R, as is with the normal scanning steppers.

[0091] (d). The stage control unit 70 synchronously controls the reticle stage RST and the wafer stage WST2 via the reticle drive portion, the X-axis linear motors 84 and 85, and the Y-axis linear motor 81. When performing this control, especially during the scanning exposure described above, the reticle stage RST and the wafer stage WST2 are synchronously controlled so that a movement velocity Vr of the reticle stage RST in the Y-axis direction and a movement velocity Vw of the wafer stage WST2 in the Y-axis direction are maintained at a velocity ratio corresponding to the projection magnification of the projection optical system PL (at a magnification of 1/4 or 1/5).

[0092] As is appreciated from the above explanation, in

the embodiment, a drive unit which synchronously moves the reticle stage RST and the wafer stage WST2 is constructed of the stage control unit 70, the reticle driving portion and the x-axis linear motors 85 and 84 and the Y-axis linear motor 81 which are controlled by the stage control unit 70. In a similar manner to this, a drive unit which synchronously moves the reticle stage RST and the wafer stage WST1 is constructed of the stage control unit 70, the reticle driving portion and the X-axis linear motors 82 and 83 and the Y-axis linear motor 80 which are controlled by the stage control unit 70.

[0093] (e). Then, different areas of the pattern area on the reticle R are sequentially illuminated with the ultraviolet pulse light, and when illumination with respect to the entire surface of the pattern area is completed, scanning exposure on the first shot area of the wafer W2 is completed. In this manner, the pattern of the reticle R is reduced and transferred onto the first shot area via the projection optical system PL.

[0094] (f). Furthermore, the blind drive unit (not shown in the drawings) synchronously controls the movement of the predetermined blades of the movable reticle blind and the movement of the reticle stage RST so as to cut off the irradiation of the ultraviolet pulse light onto areas other than the pattern area on the reticle R which has just completed scanning exposure, based on instructions from the

stage control unit 70.

[0095] (g). After the scanning exposure on the first shot area is completed as described above, the stage control unit 70 steps or step-moves the wafer stage WST2 in the X-axis direction and the Y-axis direction to the starting position for scanning exposure (acceleration starting position) on the second shot area via the X-axis linear motors 84 and 85 and Y-axis linear motor 81, based on instructions from the main controller 90. When this stepping operation is performed, the stage control unit 70 measures the positional displacement of the wafer stage WST2 in the X, Y, and θz directions real-time, based on the measurement values of interferometers 46 and 18 of the interferometer system which have the length measuring axes BI2Y and BI2X. Based on the measurement results, the stage control unit 70 controls the position of the wafer stage WST2 so that the XY positional displacement of the wafer stage WST2 moves into a predetermined state. In addition, the stage control unit 70 controls the reticle drive portion based on displacement information of the wafer stage WST2 in the θz direction, and rotationally controls the reticle stage RST (reticle fine movement stage) in order to compensate for the error in rotational displacement on the wafer side.

[0096] (h). Then, in accordance with instructions from the main controller 90, the stage control unit 70 and the

laser control unit (not shown in the drawings) control the operation of each portion as described above, and scanning exposure on the second shot area of the wafer W2 is performed, likewise as that described above.

[0097] (i). In this manner, scanning exposure on the shot area on the wafer W2 and stepping operations to expose the following shot area are repeatedly performed, and the pattern of the reticle R is thus sequentially or successively transferred onto the shot areas, on the wafer W2, as a subject to be exposed (exposure-subject).

[0098] Also, the main controller 90 controls the totalized exposure amount to be provided to each point on the wafer during the scanning exposure described above. The totalized exposure amount is controlled by performing, via the stage control unit or the laser control unit (not shown in The drawings), control of at least one of oscillation frequency (the pulse repetition frequency) of the light source (not shown in the drawings), the pulse energy per pulse emitted from the light source, the attenuation ratio of the attenuation portion within the illumination system 20, and the scanning velocity of the wafer stage and the reticle stage.

[0099] Furthermore, for example, when the movement starting position (synchronous position) of the reticle stage and the wafer stage needs to be corrected on scanning exposure, the main controller 90 instructs the stage

control unit 70 which controls the movement of each stage to correct the position of the stage in accordance with the correction amount.

[0100] In parallel with the exposure operations as is described in (a) to (i) on the wafer W2, based on the step-and-scan system, alignment operations are performed on the wafer W1 on the wafer stage WST1 side in the following manner.

[0101] (1) As a premise, the wafer stage WST1 on which the wafer W1 is mounted is to be located below the alignment system 24a (refer to FIG. 2). In this case, as shown in FIG. 2, the position of the wafer stage WST1 is measured by the interferometers 44 and 16 which have the length measuring axis BI1Y and the length measuring axis BI1X, respectively, and is measured and managed based on an alignment coordinate system set by the length measuring axes BI1Y and BI1X, with the alignment system 24a as the origin. The positional information measured here is sent to the main controller 90 via the stage control unit 70.

[0102] (2) Next, the main controller 90 controls the movement of the wafer stage WST1 via the stage control unit 70, so that four fiducial marks Ma1, Mb2, Mc, and Md, which are among the fiducial marks formed on the fiducial mark plates FMa to FMd arranged in the vicinity of the wafer holder H1, are sequentially positioned within the detection field of the alignment system 24a. By this control, each

time when the positioning is performed, the positional shift or positional deviation of the fiducial marks Ma1, Mb2, Mc, and Md in the X-axis direction and Y-axis direction (positional shift with respect to the index mark within the alignment system 24a) is measured with the alignment control unit 60 via the alignment system 24a, and the measurement results are sent to the main controller 90. The main controller 90 then obtains the coordinate values of the fiducial marks Ma1, Mb2, Mc, and Md in the alignment coordinate system, based on the positional shift amount of each fiducial mark and the positional information about the wafer stage WST1 (measurement values of the interferometers 44 and 16) at the time of each measurement, and the main controller 90 stores the results in the memory unit.

[0103] (3) The main controller 90 then calculates the X coordinates and the Y coordinates of each alignment mark on the alignment coordinate system. This calculation is made from the measurement of the positional shift amount of each of the alignment marks respectively arranged in at least three shot areas on the wafer W1 (to be more precise, at least three shot areas which are located within the squarish shaped area EA in FIG. 4 mentioned above) in the X direction and Y direction as well as from the coordinates of the wafer stage WST1 (measured with the interferometers 16 and 44) at the time of each measurement, in the same way the coordinate values of the fiducial marks Ma1, Mb2, Mc,

and Md referred to above were obtained.

[0104] (4) Next, the main controller 90 calculates the center coordinates and the rotational angle θ1 of the wafer holder H1 by the least squares method from the coordinates of the fiducial marks Ma1, Mb2, Mc, and Md in the vicinity of the wafer holder H1, which has been measured as above. Then, the main controller 90 sets or determines the coordinate system of the wafer holder H1 (hereinafter referred to as "holder coordinate system") which is an XY orthogonal coordinate system rotated by the angle of θ1, with the center coordinates of the wafer holder H1 as the origin.

[0105] (5) After setting the holder coordinate system, the main controller 90 converts the coordinates (actual measurement values) of the alignment marks on the wafer W1 on the alignment coordinate system into the coordinates on the holder coordinate system. Further, by using the converted coordinates, the main controller 90 sets or determines the arrangement coordinates of the i-th shot area (X_i, Y_i) on the wafer W1 using the model equation of statistic processing based on the Enhanced Global Alignment (EGA) method, as disclosed, for example, in the Japanese Patent Application Laid-open No. 61-44429 (and U.S. Patent No. 4,780,617 corresponding thereto).

[0106] In this case, alignment marks of shot areas belonging within the squarish area EA set by the fiducial

marks Ma1, Mb2, Mc, and Md used to determined the holder coordinate system are selected and measured. Therefore, even if the position coordinates of these alignment marks are converted to coordinates on the holder coordinate system, the coordinates can be treated as having high reliability. Accordingly, the arrangement coordinates (X_i, Y_i) determined from these coordinate values are also highly reliable. That is, it is possible to consider that the level of errors of the arrangement coordinates is same to the extent that of the measurement error of the fiducial marks Ma1, Mb2, Mc, and Md.

[0107] The arrangement coordinates (X_i, Y_i) are relative positional information about each of the shot areas on the wafer W1 with respect to the wafer holder H1, and the arrangement coordinates (X_i, Y_i) are stored in the memory unit within the main controller 90. Further, since this embodiment is based on a premise that the wafer holder H1 has a residual rotational error with respect to the X-axis and the Y-axis, the coordinate system of the wafer holder H1 is to be rotated with respect to the X-axis and the Y-axis.

[0108] In addition, since the alignment system 24a uses a broadband alignment light of a non-exposure wavelength, the fiducial marks Ma1, Mb2, Mc and Md and the alignment marks are both measured with high precision. Further, in order to quickly measure the center and the rotation angle

of the wafer holder H1, it is sufficient that only the two-dimensional measurement of at least one fiducial mark among the fiducial marks and an X-axis mark or a Y-axis mark measurement of another fiducial mark among the fiducial marks. However, as the number of the fiducial marks which is measured is greater, the measurement which can be obtained becomes more accurate since the averaging effect can be gained and it also becomes possible to consider the scaling (expansion and contraction) of the wafer holder H1. Similarly, with the alignment marks, the minimum requirement for measurement is to measure the one-dimensional position of three alignment marks among the alignment marks. However, in order to consider the scaling (in the X direction and Y direction) and the orthogonal degree error, it is preferable that the number of the shot areas to be measured is, for example, not less than three and that the number of alignment marks to be measured is not less than six by performing the conversion to a one-dimensional alignment mark.

[0109] The above-described alignment operations for the wafer W1 on the wafer stage WST1 are completed prior to the exposure operations for the wafer W2 on the wafer stage WST2 side; and the wafer stage WST1 then is made to be in a waiting state.

[0110] (6) Further, when the exposure operations for the wafer W2 is completed, the main controller 90 moves the

wafer stage WST1 to be positioned below the projection optical system PL as shown in FIG. 1, so as to perform exposure for the wafer W1. However, as it can be easily imagined from FIGs. 2 and 3, the interferometer beam indicated as the length measuring axis BI1Y strays off or is moved away from the movable mirror 96b while the wafer stage WST1 is being moved, thereby making it impossible to measure the position of the wafer stage WST1 in the Y-axis direction. Therefore, in the main controller 90, the following devise is performed so as to move the wafer stage WST1 to a position below or under the projection optical system PL. That is, the main controller 90 temporarily moves the wafer stage WST1 via the stage control unit 70, the X-axis linear motors 82 and 83 and the Y-axis linear motor 80, so that either one of the fiducial marks Ma1, Mb2, Mc or Md, for example, Ma1, is positioned within the field of the alignment system 24a. Next, the main controller 90 then servo controls the Y-axis linear motor 80, with the Y position at that time as the target value via the stage control unit 70, so that the wafer stage WST1 are made to be in a stationary state regarding the Y-axis direction; and at the same time, the main controller 90 drives the X-linear motors 82 and 83 via the stage control unit 70 so that the wafer stage WST1 moves in the +X direction by a distance corresponding to the distance between the detection center SXa and the optical axis AX

obtained in advance, while monitoring the measurement values of the interferometer 16 having the length measuring axis BI1X. By doing so, the wafer stage WST1 is moved in the +X direction; and due to this movement, the fiducial mark plate Ma1 located or positioned directly below or under the alignment system 24a is located directly below or under the projection optical system PL. As a matter of course, in parallel with moving the wafer stage WST1, the main controller 90 moves the wafer stage WST2 in the same manner as of the above-described wafer stage WST1 side via the stage control unit 70, so that the wafer stage WST2 is positioned at the wafer exchange position which is below or under the alignment system 24b, and the main controller 90 resets the interferometer 48 having the length measuring axis BI3Y immediately before any of the fiducial marks on the wafer stage WST2 become detectable with the alignment system 24b.

[0111] (7) Then, as shown in FIG. 1, the main controller 90 moves the respective mirrors 31 and 32 so that the mirrors 31 and 32 are located above the reticle marks RM1 and RM2, respectively; and makes the alignment lights having the exposure wavelength be irradiated onto the reticle marks RM1 and RM2 from the RA microscopes 41 and 42 respectively, and makes the alignment lights passing through the periphery of the reticle marks RM1 and RM2 be irradiated onto the fiducial marks Ma1 and Ma2 respectively

via the projection optical system PL. By doing so, the alignment control unit 60 detects the relative positions of the images of the fiducial marks Ma1 and Ma2 on the fiducial mark plate Ma with respect to the corresponding reticle marks RM1 and RM2, and the detection results are supplied to the main controller 90. Here, prior to the above-described detection of the relative positions, the interferometer 46 is reset at any point of time at which the interferometer beam indicated as the length measuring axis BI2Y is picked up by or arrived at the reflection surface of the movable mirror 96b, and after this point of time, the position of the wafer stage WST1 is managed on the XY coordinate system of which origin is the optical axis of the projection optical system PL defined by the length measuring axes BI2Y and BI1X (hereinafter referred to as "exposure coordinate system").

[0112] (8) Accordingly, the main controller 90 calculates the coordinate position of the fiducial marks Ma1 and Ma2 on the fiducial mark plate FMa on the exposure coordinate system and calculates the coordinate position of the projection images of the mark RM1 and RM2 of the reticle R on the wafer surface, and the main controller 90 obtains the difference therebetween, based on the detection results described above of the alignment control unit 60 and the measurement values of the interferometers 46 and 16 which have the length measuring axes BI2Y and BI1X,

respectively, at the time of detection. By doing so, the main controller 90 obtains the positional relationship between the exposure position (the projection center of the projection optical system PL) and the coordinate positions of the fiducial marks Ma1 and Ma2 on the fiducial mark plate FMa, namely the positional shift amount, based on the obtained difference.

[0113] In this case, the exposure center is the center of the images of the reticle marks RM1 and RM2, and the tilt angle of a straight line passing through the center of the images with respect to the X-axis is the tilt angle of the reticle pattern image. In this embodiment, the rotational angle of the reticle stage RST is to be corrected beforehand such that the tilt angle is substantially zero.

[0114] In addition to the measurement of the positional relationship between the exposure position (the projection center of the projection optical system PL) and the coordinate position of the fiducial marks Ma1 and Ma2 on the fiducial mark plate FMa, the main controller 90 may move the fiducial marks Mb1 to Mb3 on the fiducial mark plate FMb relative to the reticle marks formed on the reticle and measure them using one of the reticle alignment microscopes 41 (or 42) to thereby perform scaling adjustment of the interferometers of the reticle stage RST and the wafer stage WST1, namely scanning movement distance

adjustment between the reticle R and the wafer W1 during the relative scanning operations.

[0115] (9) Then, the main controller 90 calculates the offset of the holder coordinate system as described above in the X-axis direction and Y-axis direction with respect to the exposure coordinate system and the rotational angle θ2, by using the X coordinates and Y coordinates of the fiducial marks Ma1 and Ma2. Further, the main controller 90 then uses the information about the offset and the rotational angle θ2 and the arrangement coordinates (X_i, Y_i) of each of the shot areas on the wafer W1 on the holder coordinate system stored in memory in the foregoing process to calculate the arrangement coordinates (XA_i, YA_i) of each of the shot areas on the wafer W1 on the exposure coordinate system. By using the arrangement coordinates (XA_i, YA_i), the center of each shot area on the wafer W1 and the center of the pattern image of the reticle R can be made to match with high precision. Then, the main controller 90 withdraws or retracts the mirrors 31 and 32 from the optical path of the exposure light IL, and thereafter the exposure is performed for the wafer W1 on the wafer stage WST1 in the manner similar to the exposure for the wafer W2 as described above.

[0116] Note that instead of calculating only the offset as described above or calculating the rotational angle in addition to this, it is allowable that the arrangement

coordinates of each shot area on the coordinate system (exposure coordinate system) is calculated by detecting at least three fiducial marks among the fiducial marks by using either one of the RA microscopes 41 and 42 so as to obtain the X coordinates and Y coordinates of the wafer stage (fiducial marks) on the coordinate system (exposure coordinate system) when the positional shift amount of each of the fiducial marks with respect to the reticle marks is zero or a predetermined value, and then, for example, the EGA method previously described is applied. Namely, it is allowable that the coordinate values on the exposure coordinate system and the coordinate values on the holder coordinate system per each of the fiducial marks are substituted in the model equation of the EGA method, and that the error parameter is calculated by the least squares method or the like. Further, it is allowable that the arrangement coordinates of each shot area on the exposure coordinate system are calculated by substituting the arrangement coordinates of each shot area on the holder coordinate system in the model equation calculating the error parameter.

[0117] In such a manner, since the arrangement coordinates (X_i, Y_i), of each shot area on the wafer W1, on the holder coordinate system are highly reliable, each shot area on the wafer W1 can be consequently overlaid with high precision with respect to the pattern image of the reticle

R. That is, a high alignment precision (overlay accuracy) can be obtained with the exposure apparatus according to this embodiment.

[0118] On the other hand, in parallel with the exposure performed for the wafer W1 on the wafer stage WST1 side, the wafer exchange unit (not shown in the drawings) performs wafer exchange on the wafer stage WST2 at the wafer exchange position below or under the alignment system 24b. And after the wafer is exchanged, alignment operations are performed on the exchanged wafer (referred to as "wafer W'" for the sake of convenience) in a procedure similar to that as described above.

[0119] Then, at a point of time at which exposure operations on the wafer W1 is completed, the wafer stage WST1 then is moved to the position shown in FIG. 2 (below or under the alignment system 24a), and the wafer exchange by the wafer exchange unit and alignment operations described earlier are performed, whereas the wafer stage WST2 is moved to the position below or under the projection optical system PL and exposure is performed on the wafer W'. In this manner, in the embodiment, in parallel with the exposure operations on the wafer on the wafer stage WST1 (or WST2) as one of the wafer stages, the wafer exchange and alignment operations are performed on the wafer stage WST2 (or WST1)as the other of the wafer stages. Therefore, high throughput can be consequently achieved.

[0120] As described in detail so far, with the exposure apparatus 10 according to the embodiment, four fiducial mark plates FMa to FMd (or FMa' to FMd') on which a plurality of fiducial marks Ma1 to Md (or Ma1' to Md') used in (with respect to) each of the measurement sequences are formed dispersedly are arranged on the wafer stage WST1 (or WST2) in the periphery of the wafer holder such that a positional relationship is constant between the plurality of fiducial marks and the wafer holder H1 (or H2). In addition, the main controller 90 executes various measurement sequences including detection operations to detect the positional information of each fiducial mark using the alignment system 24a (or 24b), thereby making it possible to maintain performance related to the measurement. Furthermore, since the plurality of fiducial marks used in each measurement sequence are formed dispersedly on the fiducial mark plates FMa to FMd, the reference mark plates can be arranged in a small space on the wafer stage (refer to FIG. 4). Accordingly, it is possible to downsize the wafer stage, thereby reducing the footprint of the apparatus.

[0121] In addition, the fiducial marks Ma1 to Md (or Ma1' to Md') are arranged so as to be each located in the vicinity of one of the corners of the squarish shape which contains the center of the wafer holder H1 (or H2). This arrangement allows a sufficient space (distance) between

the fiducial marks and the limits of the measurement span can also be relaxed, thereby realizing improvement in the measurement accuracy. Furthermore, the center of the wafer holder H1 (or H2) is located within the squarish area enclosed with or surrounded by the fiducial marks. Accordingly, in a case that the center of the wafer holder is to be obtained based on the measurement results of the fiducial mark positions, the center point corresponds, so to speak, to the interpolation point of the fiducial mark positions. Therefore, the main controller 90 detects the position information about each fiducial mark arranged on the wafer stage by using the alignment systems and the interferometers and performs a predetermined calculation based on the positional information, thereby making it possible to obtain the holder coordinate system of which origin is the center of the wafer holder with a sufficient level of reliability. Further, the main controller 90 obtains the positional information about the alignment marks located within the squarish shape in the alignment coordinate system by using the alignment systems and the interferometers, and the main controller 90 converts the positional information into positional information in (based on) the holder coordinate system. By doing so, in a case, for example, that the wafer stage position cannot be measured with the interferometers and the position of the wafer stage cannot be managed temporarily, the main

controller 90 is capable of re-measuring the fiducial marks on a new coordinate system (exposure coordinate system) and the main controller 90 is capable of obtaining, based on the measurement results and the positional information on the holder coordinate system, the positional information about the alignment marks with high reliability based on the new coordinate system. Accordingly, the position of the wafer can be managed with good accuracy at all times, without increasing the size of the wafer stage and the footprint of the apparatus.

[0122] Further, the positions of the wafer stages WST1 and WST2 are managed on the orthogonal coordinate system such as the alignment coordinate system and the exposure coordinate system by the interferometers, and the plurality of fiducial mark plates include a first mark plate (FMa, FMa') on which a plurality of fiducial marks are formed in the X-axis direction of the orthogonal coordinate system as an elongated plate extending in the X-axis direction and a second mark plate (FMb, FMb') on which a plurality of fiducial marks are arranged in the Y-axis direction as an elongated plate extending in the Y-axis direction. Thus, by dispersing a large number of the fiducial marks depending on their usage circumstances, it is possible to reduce the size of each fiducial mark plate while maintaining their performance, which in turn makes it possible to downsize the wafer stage on which the fiducial

mark plate are arranged.

[0123] In the embodiment above, although the explanation has been made about a case that each fiducial mark is formed on the fiducial mark plates (FMa-FMd and FMa'-FMd') arranged in the periphery of the wafer holders (wafer holding members), note that this arrangement is made so as to easily secure the precision (such as the line width and the level of flatness) upon processing. However, the present invention is not limited to this, and the fiducial marks may be formed directly on the wafer stage, or on the wafer holder. Alternatively, a fiducial mark plate separated from the wafer holder may be fixed on the wafer stage.

[0124] In addition, in the embodiment above, the holder coordinate system is defined based on the coordinate values (measurement values) obtained by detecting a plurality of fiducial marks. However, it is allowable to use the coordinate values of the plurality of fiducial marks as described above to calculate the coordinate values of each fiducial mark based on, for example, the EGA method and to define the holder coordinate system from the calculation values obtained by the calculation. Alternatively, it is allowable to determine the holder coordinate system from a parameter, such as from the offset and the rotational error, which is obtained at a point of time at which the error parameter of the model equation used to calculate the

coordinate values based on the EGA method is calculated. Also, it is allowable that the coordinate values of the fiducial mark and each shot area is calculated based on the EGA method by using the coordinate values obtained by detecting at least one of the fiducial marks with the alignment systems 24a and 24b of the off-axis system and the coordinate values obtained by respectively detecting the alignment marks in at least three of the shot areas, and that based on the deviation of the coordinate values obtained by detecting at least one of the fiducial marks with RA microscopes 41 and 42 and the coordinate values calculated earlier, the coordinate values of each shot area calculated earlier is corrected to determine the above-described arrangement coordinates (X_i, Y_i).

[0125] In the embodiment, when the wafer stage WST1 is moved from the position below or under the alignment system 24a (the state shown in FIG. 2) to the position below or under the projection optical system PL (the state shown in FIG. 1) (or when the wafer stage WST2 is moved from the position below the alignment system 24b (the state shown in FIG. 1) to the position below the projection optical system PL (the state shown in FIG. 2), it is preferable that the positional relationship between the wafer holder and the wafer, and consequently between the fiducial mark plate and the wafer is not changed as less as possible. Therefore, it is allowable to provide, on the wafer stage WST1 (or

WST2) at a portion at which the wafer holder and the fiducial mark plates are to be mounted, a heating and cooling element such as a heater of a Peltier element and a temperature control unit constructed of a temperature measurement element such as a thermistor so that the temperature control unit maintains the temperatures of the wafer holder, wafer, and fiducial mark plates at a constant level.

[0126] Note that in order to disperse the fiducial marks depending on the measurement sequences, it is, as a matter of course, possible to use a dispersion method different from the method adopted in the embodiment above.

[0127] Further, in the embodiment above, the four fiducial mark plates are arranged in the periphery of the wafer holder. However, the present invention is not limited to this, and it is possible to adopt an arrangement method as shown in FIGs. 5 and 6. In the following, an explanation will be given about a modified example of the arrangement of the fiducial marks, with reference to FIGs. 5 and 6.

[0128] FIG. 5 shows a wafer stage WST' according to a first modified example. As appreciated from FIG. 5, there are provided three fiducial mark plates FMe, FMf and FMg on the periphery of the wafer holder on the wafer stage WST'. These three fiducial mark plates FMe, FMf and FMg are arranged substantially at the vertex of a triangle EA'

which contains the center of the wafer holder Hc' therewithin. Among these fiducial mark plates, on the fiducial mark plate FMe, which is arranged on the lower side (-Y side) of the wafer W in FIG. 5, two fiducial marks Me1 and Me2 which can be measured at the same time with a pair of RA microscopes constructing a twin lens, in a similar manner as the fiducial mark plate FMa shown in FIG. 4; and on the remaining fiducial mark plates FMf and Fmg other than the fiducial mark plate FMe, fiducial marks Mf and Mg for defining the holder coordinate system are respectively formed, in a similar manner as the fiducial mark plates FMc and Fmd shown in FIG. 3.

[0129] In the case of the modified example shown in FIG. 5, similar to the embodiment above, the center of the wafer holder is located within the triangular area EA' enclosed with or surrounded by the fiducial marks. Therefore, in a case that the center of the wafer holder is obtained based on the measurement results of the fiducial mark positions, the center point corresponds, so to speak, to the interpolation point of the fiducial mark positions. Accordingly, the main controller 90 uses the alignment systems and the interferometers to detect the position information about each fiducial mark arranged on the wafer stage and performs a predetermined calculation based on the positional information, thereby making it possible to obtain the holder coordinate system of which origin is the

center of the wafer holder with a sufficient level of reliability. Further, by performing the EGA calculation using the positional information about the alignment marks provided along the shot area located within the area EA', it is possible to enhance the reliability of the error parameters (X and Y offset, rotation, orthogonal degree, X and Y scaling) which are the calculation results than in a case that the EGA calculation is performed using the positional information about the alignment marks provided along the shot area located outside the area EA'. This point is similar also with respect to the embodiment described above.

[0130] Furthermore, in an arrangement in which the space (spacing distance) between the fiducial mark plates is great only in a predetermined direction, the measurement accuracy in the so-called EGA measurement decreases since the space in a direction perpendicular to the predetermined direction becomes small. Therefore, it is preferable to arrange the fiducial marks (fiducial mark plates) on the periphery of the wafer holder at angular intervals which are substantially equal.

[0131] The arrangement of the fiducial mark plates on the wafer stage is not limited to the modified example or the embodiment above, and it is sufficient that the fiducial mark plates are arranged such that at least three fiducial marks among the fiducial marks are positioned at

the vertex of a polygon; and it is possible to set the number and the arrangement position of the fiducial mark plates arbitrarily.

[0132] FIG. 6 shows a wafer stage WST" according to a second modified example. As appreciated from FIG. 6, the wafer stage WST" according to the second modified example is characteristic that two fiducial mark plates FMh and FMi are arranged in the vicinity of the wafer holder.

[0133] These two fiducial mark plates FMh and FMi are arranged on opposite sides with respect to the center of a straight line EA" which passes through the center of the wafer holder. Further, on the fiducial mark plates FMh and FMi, fiducial marks Mh and Mi for determining the holder coordinate system are formed, in a similar manner with the fiducial mark plates FMc and Fmd shown in FIG. 3.

[0134] By arranging the two fiducial mark plates in such a manner, it is possible to make the space or spacing distance between the fiducial marks be great to an extent same as the diameter of the wafer holder and to relax the limits of the measurement span, thereby making it possible to improve the measurement accuracy. Further, the center of the wafer holder is located or present on the straight line which links the two fiducial marks. Thus, in a case that the center of the wafer holder is obtained based on the measurement results of the fiducial mark positions, the center point corresponds to the interpolation point of the

fiducial mark positions. Accordingly, the main controller 90 uses, for example, the alignment systems and the interferometers to detect the positional information about each fiducial mark arranged on the wafer stage and performs a predetermined calculation based on the positional information, to thereby make it possible to obtain a holder coordinate system of which origin is the center of the wafer holder with a sufficient level of reliability. Further, the main controller 90 is capable of obtaining the positional information about the alignment marks located on the straight line on the wafer, for example, on the alignment coordinate system, by using the alignment systems and the interferometers, and the main controller 90 converts the obtained positional information into positional information on the holder coordinate system. By doing so, for example, even in a case that the position of the wafer stage cannot be managed temporarily, the main controller 90 is capable of re-measuring the fiducial marks based on a new coordinate system (exposure coordinate system), is capable of obtaining, based on the measurement results and the positional information on the holder coordinate system, the positional information about the alignment marks with high reliability on the new coordinate system. Accordingly, it is possible to control or manage the position of the wafer with good accuracy at all times, without increasing the size of the wafer stage and the

footprint of the apparatus. In this case, since the two fiducial marks are symmetrical to the center of the wafer holder, it is possible easily calculate, for example, the center coordinates and the rotational angle of the wafer holder. Further, for example, in a case that the position of the wafer stage is managed with the interferometers based on the orthogonal coordinate system, it is possible to measure the mark position in both coordinate axis directions of the orthogonal coordinate system with a similar level of accuracy by making the straight line linking the two fiducial marks tilt at an angle of around 45 degrees with respect to the coordinate axes of the orthogonal coordinate system. Furthermore, although the exposure apparatus shown in FIG. 1 had two wafer stages, it is also allowable to provide a single stage, and to adopt arbitrary arrangement or construction, except for the arrangement or construction of the fiducial mark plates. Moreover, the fiducial marks formed on each fiducial mark plate may either be one-dimensional or two-dimensional, or a combination of both.

[0135] Furthermore, in the above-described embodiment, the surface of the fiducial mark plates is set at a height substantially same as the height of the wafer surface. However, it is not necessarily indispensable that the fiducial mark plates are arranged so that the surface thereof is at the same height as that of the wafer surface.

Further, in the embodiment above, the two alignment systems 24a and 24b are arranged on the both sides of the projection optical system and the wafer stage WST1 is moved between the alignment system 24a and the projection optical system PL and the wafer stage WST2 is moved between the alignment system 24b and the projection optical system PL. However, as disclosed for example in International Publication No. WO98/40791, it is allowable to provide an arrangement (construction) in which only one of the alignment systems 24a and 24b is provided and the two wafer stages are switched alternately between the alignment system and the projection optical system PL. Moreover, when the marks on the wafer are detected with the alignment system 24a and 24b on the wafer stage WST1 or WST2 as one of the wafer stages in parallel with the exposure on the wafer at the wafer stage WST2 or WST1 as the other wafer stage, it is allowable, for example, that step information about the shot areas on the wafer is detected using a sensor having a same construction as that of an AF sensor used in the projection optical system PL.

[0136] In the embodiment above, ultraviolet light such as the KrF excimer laser or the ArF excimer laser, or a pulse laser in the vacuum ultraviolet region such as the F_2 laser is used as the light source. However, the present invention is not limited to this, and it is allowable to use other vacuum ultraviolet light such as the Ar_2 laser

(output wavelength: 126 mm). In addition, for example, as the vacuum ultraviolet light, it is allowable to use, other than the laser beam emitted from each of the above-described light sources, a harmonics generated by amplifying a single wavelength laser beam in the infrared or visible region oscillated from a DFB semiconductor laser or a fiber laser with an erbium (Er) (or both erbium and ytteribium(Yb))-doped fiber amplifier and converting the wavelength to an ultraviolet light with a non-linear optical crystal.

[0137] In the embodiment above, an explanation has been given about a case in which the present invention is applied to the scanning exposure apparatus based on the step-and-scan system or the like. As a matter of course, however, the application scope of the present invention is not limited to this. Namely, the present invention can be suitably applied to a reduction projection exposure apparatus based on the step-and-repeat system.

[0138] The exposure apparatus in the embodiment above can be made by incorporating the illumination optical system constructed of a plurality of lenses and the projection optical system into the main body of the exposure apparatus and by performing optical adjustment, while incorporating the reticle stage RST constructed of various mechanical components and the wafer stage into the main body of the exposure apparatus, connecting the wiring

and piping, and further performing total adjustment (electrical adjustment, operational adjustment, etc). The exposure apparatus is preferably made in a clean room in which temperature, degree of cleanliness, and the like are controlled or managed.

[0139] The present invention is not limited to the exposure apparatus for producing semiconductors, but can also be applied to an exposure apparatus which transfers a device pattern onto a glass plate used to manufacture displays including liquid crystal display devices or the like, an exposure apparatus which transfers a device pattern onto a ceramic wafer used to manufacture thin-film magnetic heads, and an exposure apparatus used to manufacture pick-up devices (such as the CCD), micromachines, DNA chips, or the like. In addition, the present invention can be applied to an exposure apparatus which transfers a circuit pattern onto a glass substrate or a silicon wafer to manufacture reticles or masks used in not only an exposure apparatus for microdevices such as the semiconductors, but also in an exposure apparatus such as optical exposure apparatus, EUV exposure apparatus, X-ray exposure apparatus and electron beam exposure apparatus. With respect to an exposure apparatus which uses the DUV (Deep UltraViolet) light or VUV (Vacuum UltraViolet) light or the like, a transmission type reticle is normally used, and as the reticle substrate material such as silica glass,

fluorine doped silica glass, fluorite, magnesium fluoride, or crystal is used. Furthermore, proximity X-ray exposure apparatus, the electron beam exposure apparatus, and the like use the transmission type mask (stencil mask, membrane mask), and as the mask substrate, silicon wafers or the like are used.

[0140] Although the above-described embodiment and the modified examples of the present invention are the presently preferred embodiment and modified embodiments thereof, those skilled in the art of lithography systems will readily recognize that numerous additions, modifications, and substitutions may be made to the above-described embodiment and modified embodiments without departing from the spirit and scope thereof. It is intended that all such modifications, additions, and substitutions fall within the scope of the present invention, which is best defined by the above-described claims.

[0141]

[EFFECT OF THE INVENTION]

As described above, according to the stage units defined in claims 1 to 4 respectively, an effect is obtained that the downsizing of the unit can be achieved while maintaining the measurement function.

[0142] Further, according to the exposure apparatuses defined in claims 5 to 19 respectively, an effect is

obtained that the downsizing of the wafer stage and the reduction of the footprint of the apparatus can be achieved. In particular, according to the exposure apparatuses according to claims 5 to 19 respectively, an effect is also obtained that the position of the substrate can be controlled or managed with good precision at all times, in addition to the effect described above.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[FIG. 1] FIG. 1 is a view showing a schematic arrangement of an exposure apparatus in an embodiment according to the present invention.

[FIG. 2] FIG. 2 is a perspective view showing the positional relationship between two wafer stages, a reticle stage, a projection optical system, and an alignment system.

[FIG. 3] FIG. 3 is a planar view showing the arrangement of the stage unit in FIG. 1.

[FIG. 4] FIG. 4 is a view showing a specific arrangement method of the fiducial mark plates on the wafer stage.

[FIG. 5] FIG. 5 is a planar view showing the wafer stage according to the first modified example.

[FIG. 6] FIG. 6 is a planar view showing the wafer stage according to the second modified example.

[EXPLANATION OF REFERENCE NUMERALS]

10: exposure apparatus

16, 18: X-axis interferometer (a part of the position measurement unit)

24a, 24b: alignment system (mark detection system)

28: reticle interferometer system (mask side position measurement unit)

41, 42: reticle alignment microscope (mask-mark detection system)

44, 46, 48: Y-axis interferometer (a part of the position measurement unit)

70: stage control unit (a part of the drive unit)

81: Y-axis linear motor (a part of the drive unit)

84, 85: X-axis linear motor (a part of the drive unit)

90: main controller (controller)

FMa to FMd, FMa' to FMd': fiducial mark plate

H1, H2: wafer holder (substrate holding member)

IL: exposure light (energy beam)

Ma1 to Md: fiducial mark

W1, W2: wafer (substrate)

WST1, WST2: wafer stage (substrate stage)

[ABSTRACT]

[PROBLEM TO BE SOLVED] To downsize a substrate stage and to reduce footprint of apparatus.

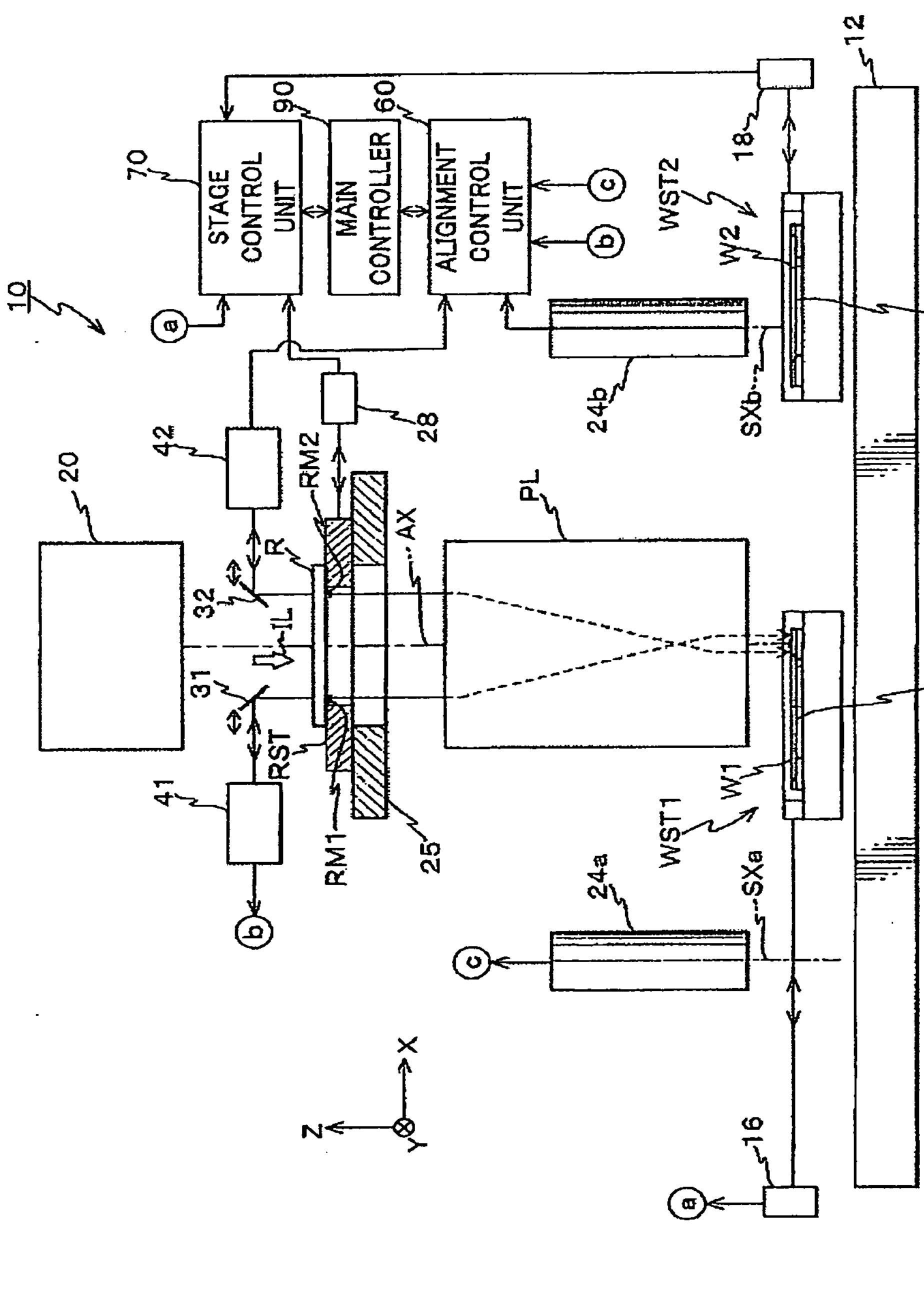
[MEANS TO SOLVE PROBLEMS] A plurality of fiducial mark plates (FMa to FMd, FMa' to FMd'), on which a plurality of fiducial marks are dispersedly arranged with respect to each of measurement sequences using the fiducial marks, are arranged on the periphery of a substrate holder on the substrate stage (WST1, WST2) such that the positional relationship between the fiducial marks and the substrate holder is made to be constant. This makes it possible to provide the fiducial mark plates on the substrate stage at a small space therein. In addition, the main controller performs various measurement sequences which include a detection operation detecting the positional information about each of the fiducial marks by using the mark detection system. Accordingly, it is possible to downsize the substrate stage and consequently to reduce footprint of the apparatus, while maintaining the measurement functions.

Continued from front page

F Terms (Reference)

5F031 CA02 CA05 CA07 HA13 HA16
HA53 HA57 JA04 JA06 JA14
JA17 JA22 JA28 JA29 JA32
JA38 KA06 KA07 KA08 LA03
LA08 MA27 NA02
5F046 BA04 BA05 CC01 CC16 CC19
EB03

【Fig. 1】



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R
RST
RM1
RM2
25
AX
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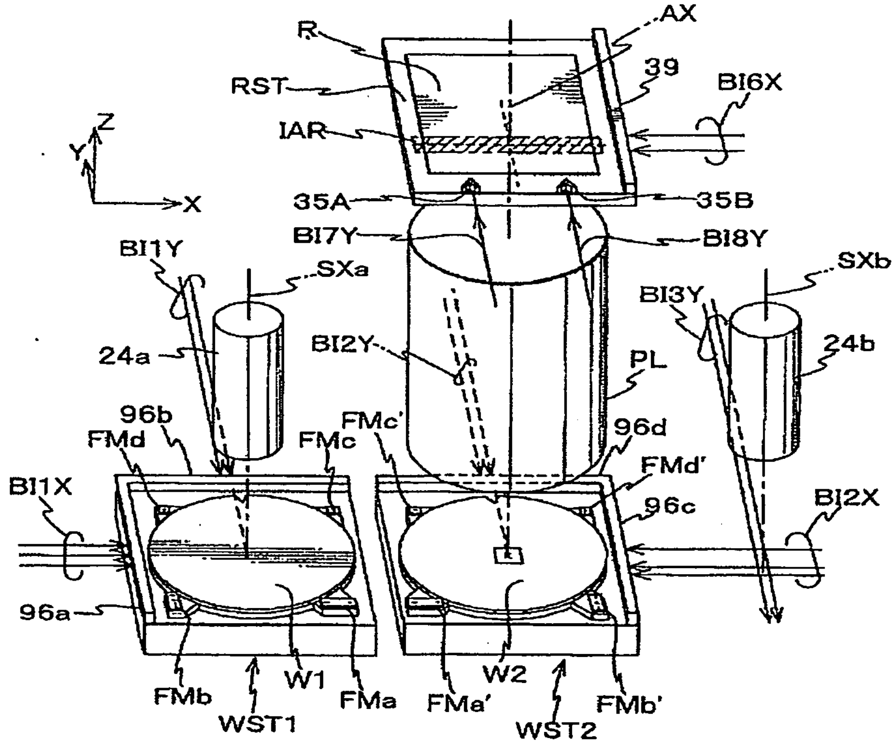
PL
24a
24b
SXa
SXb
WST1
WST2
W1
W2
H1
H2
16
18
12
70
STAGE CONTROL UNIT
90
MAIN CONTROLLER
60
ALIGNMENT CONTROL UNIT
a
b
c
Z
X
Y

【Fig. 2】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24b
BI2Y
PL
96b
FMd
FMc
FMc'
96d
FMd'
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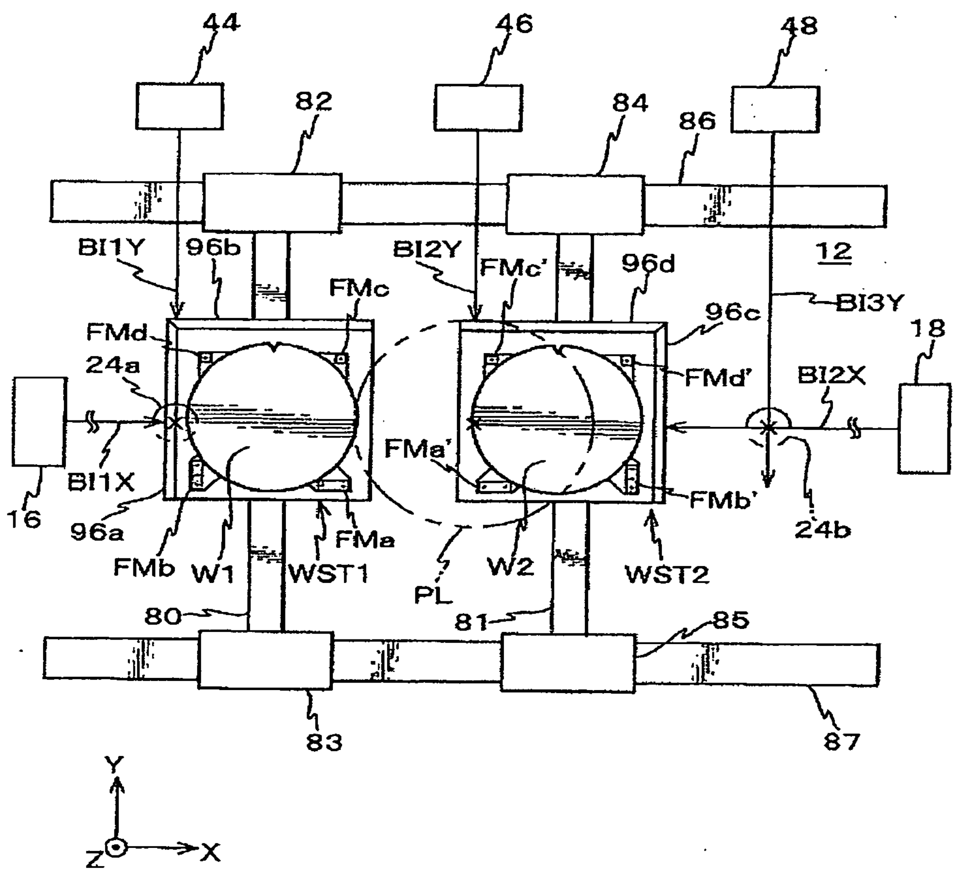
FMb
W1
FMa
FMa'
W2
FMb'
WST1
WST2

【Fig. 3】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FMd'
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BI2X
FMa'
BI1X
FMb'
16
96a
FMa
24b
FMb
W1
WST1
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W2
WST2
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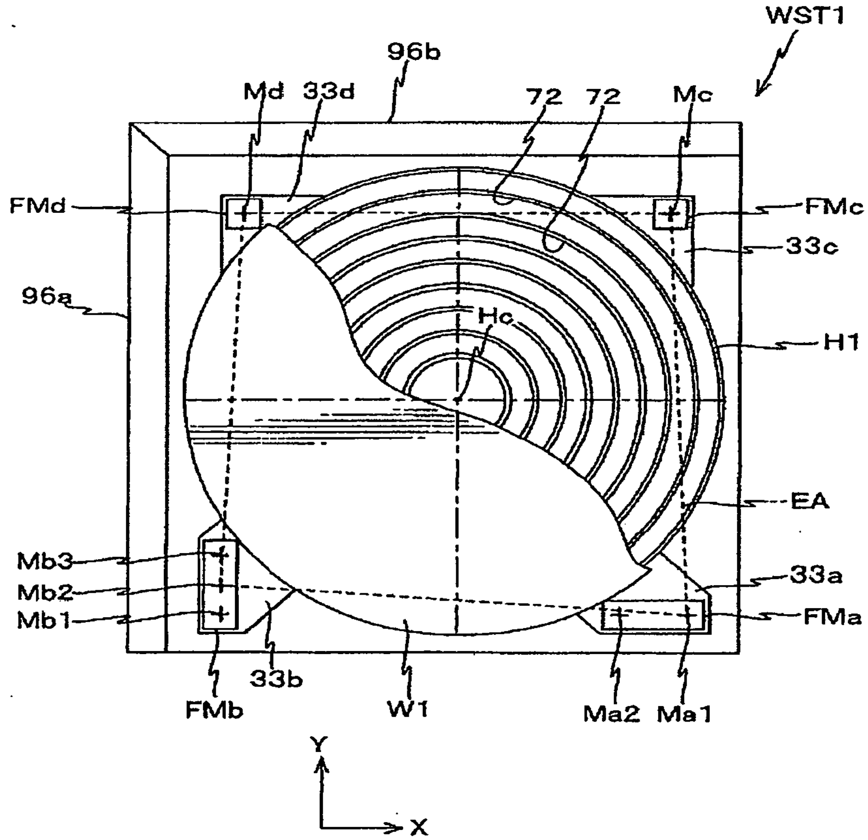
Z
X

【Fig. 4】



WST1
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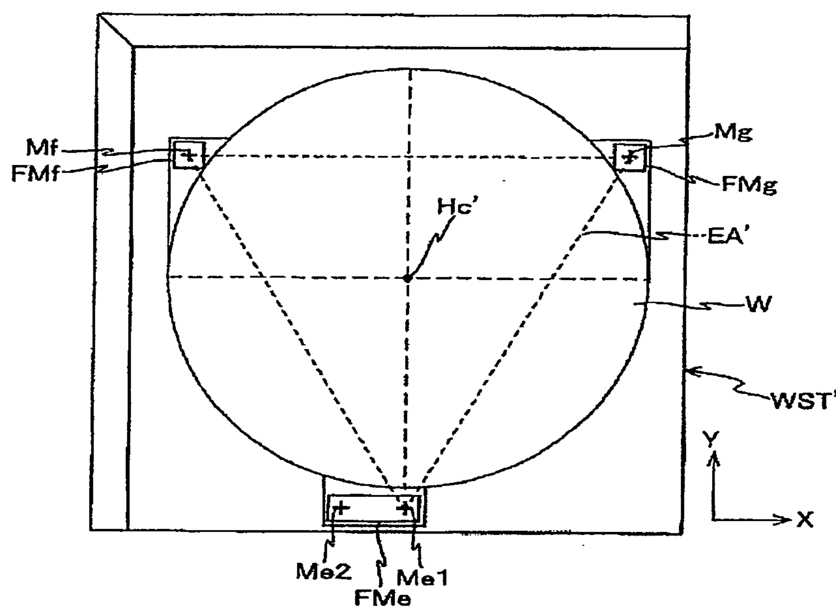
Md
33d
72
72
Mc
FMd
FMc
33c
96a
Hc
H1
EA
Mb3
Mb2
Mb1
33a
FMa
33b
FMb
W1
Ma2
Ma1
Y
X

【Fig. 5】



【Fig. 6】